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Technological change: the case of corn production in the Argentine pampas

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Technological change: The case of corn production in the Argentine pampas

by

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CHAPTER I. INTRODUCTION

Nature of the Problem

Corn is a crop with a high production potential when its requirements for growth are met, as seems to be the case in some parts of the Pampean region of Argentina. The predominance of the Pampean region in crop production with respect to the other regions of the country is mainly due to the climate and soil conditions. This area has provided most of the products that have characterized Argentina as one of the larger exporters of agricultural products in Latin America.

Hybrid corn of the "flint type" is mainly planted in the Pampean region. It occupies about 4 million hectares, which is approximately 20 percent of the land devoted to crops. A large proportion of the corn produced in the region is exported. During the 1965-1970 period Argentine shares of the corn world market varied between 11 and 19 percent, depending on weather conditions (16, 17).

Given the advances in the understanding of the environmental factors affecting corn production, the development of better management praçtices, highly fertilizer-responsive hybrids, higher rates of fertilization and pesticides applied and the corresponding reduction in cost of these inputs in the developed and developing countries, Argentina will have to increase corn yields substantially if she wants to maintain her competitive position in the world corn market.

Continuous production without any use of chemical fertilizer and inappropriate soil management practices in the region have led to substantial reductions in soil fertility levels and physical conditions keeping Argentine average corn yields level during the last 40 years.

Reca (42) found that corn yields in the Pampean region presented a negative and weak trend during the 1924-1944 period and a positive trend during the 1944-1965 period, which was barely enough to cancel out the opposite trend prevailing in the first period.

During part of the 1944-1965 period Argentina went through a process of industrialization and import substitution characterized by a rapid movement of labor from the agricultural sector to urban areas.[1] During that period mechanization in the agricultural sector, adoption of hybrid corn seed and 2,4-D took place merely compensating the decrease in corn yields during the previous period. Despite the development of better hybrids and varieties in corn and other crops total agricultural output increased at very low rates.

During the 1950-1969 period, total agricultural output

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[1]Approximately 80 percent of the population now lives in urban areas.

(including forestry and fishery products) increased at an average annual rate of 1.5 percent,[1] slightly below the population rate of growth. This, together with the increase in income of urban population, has caused domestic consumption to rise and has reduced exports from the agricultural sector.

Ninety percent of total Argentine exports and the import capacity of the industrial sector for raw materials and capital goods depends on the performance of the agricultural sector.

In explaining the low rate of growth of the agricultural sector some of the studies have emphasized the lack of economic incentives toward the sector. Reca (42) found that the low progress in the export oriented agriculture of Argentina (the Pampean region) was largely due to the lack of economic incentives. Prices were the result of government policy, not a result of the free operation of the market.

In a recent study Martinez (31) provides additional explanation of the relative stagnation of the sector. He attempted to identify the factors influencing the demand and supply of land-saving innovations like fertilizer.

Aguirre (1) studied the costs and benefits of alternative policies for nitrogen fertilizer in Argentina.

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[1]The rates of growth have been computed using Banco Central data (3).

Through a policy of import substitution and industry protection heavy duties are imposed on imports of nitrogen fertilizer resulting in domestic prices above the international market.

de Janvry (9), using data from fertilizer experiments conducted in Argentina, finds that even at the actual high prices of nitrogen and considering a certain level of risk aversion, low levels of fertilization will have high returns per hectare on nearly half of the corn and wheat acreages planted in Argentina.

What is difficult to understand is the fact that only 0.2 percent of the area planted with corn in 1968 was fertilized. de Janvry (9) attributes the lack of use "to the unavailability to farmers of technical and economic information".

The unfavorable price relationship faced by Argentine farmers is one of the reasons for the low use of nitrogen fertilizer. Another reason is the lack, until recently, of sound research along this line.

Fertilizer trials conducted as early as 1962, with many uncontrolled factors and poor interpretation by the agronomists, led to the conclusion that corn response to nitrogen fertilizer was random depending on favorable weather conditions. Based on those results research on developing a package of practices including highly fertilizer-responsive hybrids was not undertaken. Research was directed to demonstrate the benefits of proper adjustment and timing of the actual production practices and the benefits of using green manure to restore soil fertility.

Chemical fertilizer was ruled out as a means of increasing corn yields and research has been published explaining that the poor response to fertilizer compared to other countries was due to special weather and soil conditions prevailing in the Argentine Pampas. This has resulted in a lack of government policy to reduce the price of fertilizer and a lack of distribution of the information to the farmers.

To increase corn yields in the Pampean region, INTA[1] started a plan (24) in the counties (departamentos) of Caseros and Constitucion in Santa Fe province. The objective of this program is to increase corn yields in the area by 10 percent, with respect to the 1960-1970 average,[2] in a period of five years. The program consists of selecting demonstrator farmers to use production practices[3] which

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[1]Instituto Nacional de Tecnologia Agropecuaria (National Research and Extension Agency).

[2]During the period 1960-1970, the average corn yield for Caseros county was 2732 kilograms per hectare harvested (43.8 bu/A) (34).

[3]These production practices consist of a fine seedbed preparation, correct adjustment of corn planter in order to obtain an optimum plant population and distribution, and proper cultivation after planting. On low soil fertility fields green manure before planting corn would be used.

under experimental conditions proved to give higher yields.

In order to know the actual situation in the area a survey was carried out during March-May of 1972. Specific questions needed for this study were included in the questionnaire.

This study will evaluate the practices recommended and expected gains in corn yields compared to results with nitrogen fertilization. It will be limited to Caseros county.

Caseros county is a good representation, in terms of farm size, land tenure, level of mechanization, mix of activities and weather conditions, of the main corn producing area of the Pampean region.

Objectives of this Research

There are three major objectives in this study.

1. To determine the feasibility of different types of farmers adopting nitrogen fertilizer.
2. To determine factors which could be limiting nitrogen fertilization to achieve its full potential.
3. To determine the gains in production by removing the limiting factors.

These objectives will be accomplished in part by the use of mathematical programming techniques, which will enable us through the use of parametric routines to detect at what price relationship new technology will be profitable. Also, the model will provide information about the gains that can be obtained before the already available technology in Argentina becomes limiting. This study will be based on the survey data and information provided by INTA researchers and extensionists of Caseros county in Santa Fe province.

Accomplishing the first objective will allow us:

a. to identify what the impact of the new technology will be in the actual farm plans at different factor product price relations;

b. to estimate the income foregone by deviating from the optimal plan;

c. to estimate changes in farm income, production and returns to factors of production to be realized by adopting the new technology compared with present conditions.

The second objective will enable us to detect the existence or not of a package of practices and favorable weather conditions which will allow heavier rates of fertilization for a given factor-product price relationship.

The third objective will enable us to determine the gains in production and farm income that can be obtained through investment in research and extension programs.

Program of Study

Following this introductory chapter, Chapter II presents information about the study area and survey data describing the production activities carried out by the farmers during the 1971-1972 period covered by the survey.

In Chapter II is discussed some of the factors in terms of weather and soil conditions, that have been identified by Argentine researchers as limiting factors to corn response to fertilizer. Chapter III describes the now readily available corn technology in terms of production practices. Production practices that have proven successful under experimental conditions are compared to practices followed by the farmers in the area of study. Corn fertilizer responses estimated from experiments carried out in Argentina are compared to the U.S. and differences between both sets of data analyzed. Chapter IV presents the programming model for two farm types. The first model attempts to represent the activities carried out by an average farm in the study area with cattle activities. The second model represents a farm in which only cropping activities are being carried out. Both models are optimized subject to some subjective restraints in order to represent the production relationships during the period covered by the survey.

Farms with cattle activities through rotations with permanent pastures partially restore soil fertility level.

It is hypothesized that they will exhibit a different behavior toward the adoption of chemical fertilizer.

Chapter V presents changes in optimum farm plans when improved corn production technology activities proposed for the area are introduced into the model for both farm types. Crop rotations including green manure compete for resources with actual rotations followed by the farmers and nitrogen fertilized corn activities. Optimum farm plans for different corn-beef-fertilizer price relationships are presented. Finally, the impact on actual farm plans is analyzed assuming the development of highly fertilizer-responsive varieties, use of preemergence herbicides and changes in production practices.

Finally, Chapter VI presents the summary and conclusions of the study.

CHAPTER II. AREA OF STUDY AND SURVEY DATA

As a background for the empirical part of this study, a brief description of the main corn producing areas of Argentina and survey information of the study area are presented in this chapter. This chapter will also discuss research on corn and some of the factors identified as limiting corn fertilizer response in Argentina.

Corn Producing Regions

The Pampean region can be subdivided into three corn regions according to their yield potential (34). During the 1960-1970 period, these three regions made up 74 percent of the area planted with corn in Argentina and provided 87 percent of the total corn production. The average total area planted under corn for this period was 3,920,000 hectares with a total production of 6,325,000 tons. The average yield per hectare harvested was 1,977 kilograms.

Region 1 is the largest producer in hectares planted and corn production, followed by Region 3C and Region 2, in that order.

Region 1 is a selected part of the Pampean region which appears to be uniquely suited to the production of corn. Caseros county, in which the survey was conducted, belongs to this region. The region consists of parts of Buenos

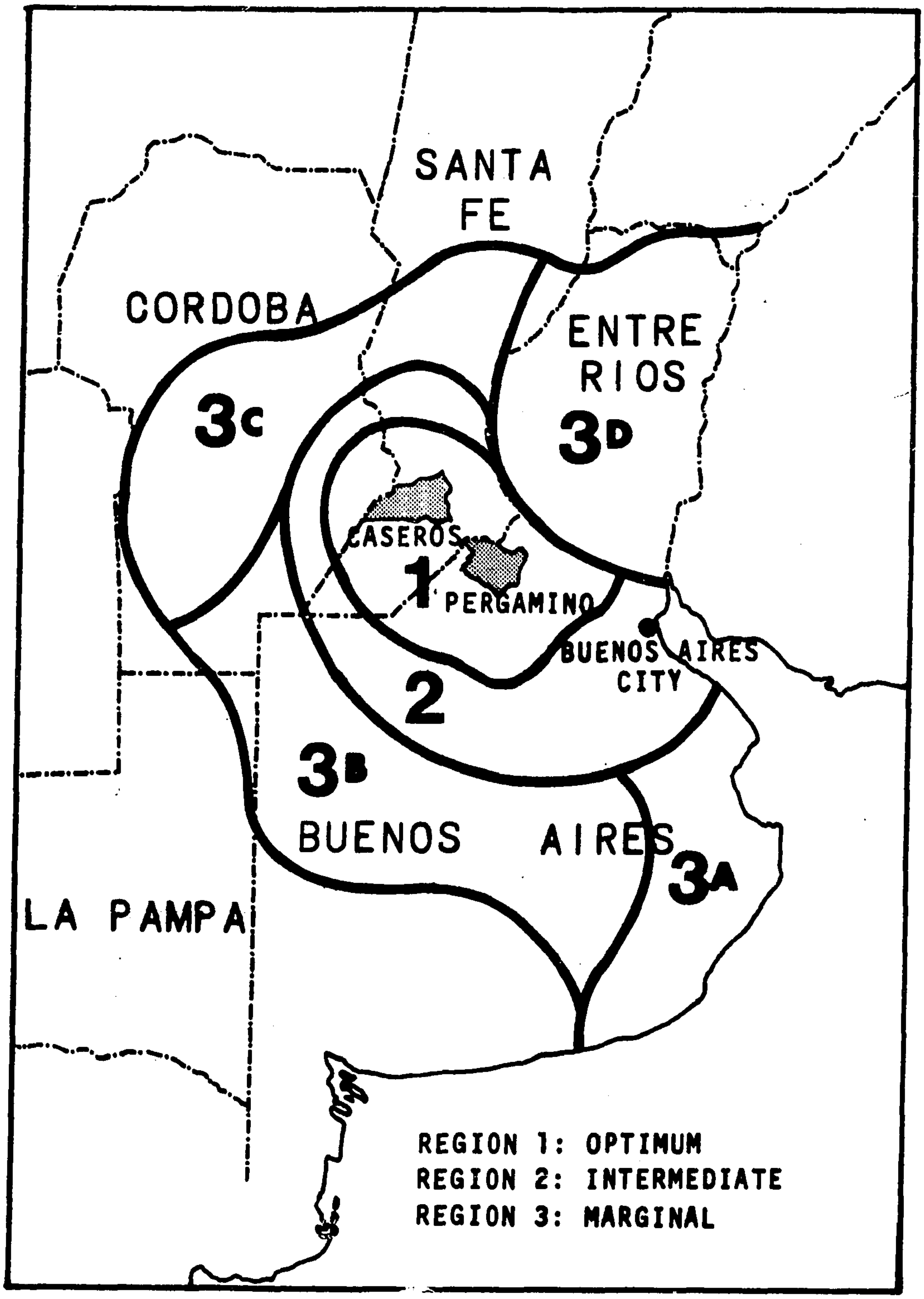

Figure 1. Corn producing regions

Aires, Santa Fe and Cordoba provinces, with an area of approximately 6,700,000 hectares. It is traditionally the corn producing area contributing 33 and 53 percent, respectively, of the total area and corn production of Argentina. This region devotes 19.4 percent of its area to corn production with an average yield of 2,757 kg per hectare harvested during the 1960-1970 period.

The Pampeana region receives a varying amount of rain, from 32 to 40 inches, decreasing from east to west. Highest rainfall amounts tend to be during the corn growing season (September to March). Differences in corn yields of Region 1 with respect to other regions are mainly due to soil and weather conditions.

Region 2, even though weather conditions are not unfavorable for growing corn, accounts for only 7.6 and 8.7 percent respectively of the total area and corn production of Argentina. The southern part of this region includes Buenos Aires and La Plata cities, which encourages a high specialization in dairy and vegetable production. This in part limits the area devoted to corn production.

Region 3 contributes with 33 and 25 percent of the total area and corn production of Argentina. This region has been subdivided into four subregions, representing different soil and weather conditions.

Subregion 3A presents a similar average yield and a lower coefficient of variation than subregion 3C but only devotes 1.6 percent of its area to corn production, compared to 8.1 percent in subregion 3C. In the northern part of this subregion soils are not as deep as in subregion 3C presenting some drainage problems. Dairy and beef cow-calf operations prevail with respect to cropping activities. The southern part of this subregion has a shorter frost-free period than subregion 3C. The development of hybrids with a shorter growing cycle could be a possibility for this area to increase corn production.

Subregion 3B represents in its southern part characteristics of weather and soil conditions comparable to subregion 3A. Moving north-west along this subregion, rainfall during the corn growing season seems to be limiting corn yields.

In subregion 3C high temperatures during the flowering and grain filling stages and lower rainfall precipitation seem to increase corn yield variability.

Description of the Study Area

The department (county) of Caseros is located in Santa Fe province in the north-west of region 1. Due to its proximity to the Rosario and Buenos Aires[1] docks and good

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[1]Caseros county is approximately 70 and 200 miles from Rosario and Buenos Aires docks respectively.

transportation systems to ports, most of the corn produced in the region is exported.

Climate

Rainfall amounts to about 21 inches from corn planting to maturity (September to February) and, with good management practices, it is possible to store 6 to 12 inches of moisture during the winter period for the coming corn crop. Rainfall during the critical corn growing stages (November-January) ranges from 10 to 12 inches. (See Table 2.1.)

Corn is mainly planted during the first two weeks of September and it is not uncommon to have late frosts and cold weather in October.

Farm size and land tenure

Data from the 1960 census shows the largest concentration of farms in the range from 25 to 100 hectares.

The data in Table 2.2 show a tendency for the very small and the very large farms to reduce in number. The average farm size was 92 hectares and 74 percent of the farms were below 100 hectares in 1960.

Table 2.3 shows the number of hectares under different tenancy systems.

Since 1960 a large number of producers who were tenants have purchased land and have become owners. In 1967 a law revoked the extensions of rural leases that had existed

Table 2.1. Average temperature and rainfall[ab]

Month	Average Temperature °C	Rainfall mm	Freq. of Days With Frost
January	23.9	108.9	
February	23.6	99.0	
March	19.7	137.5	
April	16.6	84.7	.3
May	13.3	50.8	1.4
June	10.8	33.6	5.8
July	9.7	46.9	7.2
August	11.0	25.6	6.8
September	13.7	55.0	1.7
October	17.2	77.8	.4
November	20.1	91.0	
December	22.8	101.0	
Annual	16.9	911.8	

[a]Source: Servicio Meteorologico Nacional (31, p. 144).

[b]The data corresponds to Casilda Metorological Station in Caseros county.

Table 2.2. Number of farms stratified by size[a]

Census	No.of Farms	Total ha	Strata Size in Hectares							
			5	5-25	25-100	100-200	200-1000	1000-2500	2500-5000	5000-10000
1947	3789	332,674	280	445	2073	801	179	6	1	4
1960	3786	347,964	200	489	2127	736	207	12	4	-

[a]Source: Censos Agropecuarios Nacionales, 1947 and 1960 (13, 14).

Table 2.3. Number of hectares and proportions of land in ownership and tenancy[a]

Department	Caseros
No. of Farms	3,786
Hectares Total	347,964
Owner Operated Hectares	193,400
Percent	55.6
Tenant Hectares	128,498
Percent	36.9
Share Cropper Hectares	9,272
Percent	2.7

[a]Source: Censo Agropecuario Nacional 1960 (14).

since the 1940's. Those extensions automatically renewed rental contracts, restraining landlords from evicting tenants. It was common before the 40's for large land owners to rent part of their land for periods of four to five years after which the tenant or share cropper left the land planted with alfalfa for beef production. A long-run effect of this law was restriction of the supply of high soil fertility land, devoted mainly to cattle production, by the large land owners. Tenants and owner operated small farms faced an inelastic supply of land and were therefore forced into a very intensive use of their land.

The law enacted in 1967 established long-term bank credit for purchasing the land. It is expected that this law will change the actual land tenure system and increase the proportion of land planted under share cropping.

Area planted and yields

The two main crops in the area are corn and wheat. Sunflower is planted after harvesting wheat, as a double cropping activity.

Soybean as a double cropping activity has become more important in the area since 1969. This is mainly due to the establishment of a support price and the efforts of the INTA extension agent in the area. Recently soybean has been declared a crop of national interest with a very high support

Table 2.4. Area planted and yields for main crops during the 1962-1972 period[a]

Year	Corn		Wheat	
	Area Planted th. has	Yield Per Hectare kilograms/ha	Area Planted th. has	Yield Per Hectare kilograms/ha
62/63	85.	2051	138.5	1970
63/64	88.5	2900	130.	1400
64/65	86.	2300	119.5	2250
65/66	90.	3100	100.	1600
66/67	95.	3500	95.	980
67/68	104.	3044	88.	1300
68/69	130.	2795	80.	1053
69/70	140.	3208	72.	1600
70/71	136.	3669	67.	1800
71/72[b]	155.	2300		

[a]Source: Ministerio de Agricultural y Ganaderia (35).

[b]Data on wheat planted and yield was not recorded.

Sunflower		Soybean	
Area Planted th. has	Yield Per Hectare kilograms/ha	Area Planted th. has	Yield Per Hectare hilograms/ha
16.	700	1.4	1095
17.5	699	.35	800
38.	750	.45	812
30.	796	.20	880
37.	1000	.25	1200
26.	1249	--	--
27.	904	--	--
28.	1000	4.5	1200
22.	750	5.	1723
18.	588	15.	1250

price to promote its production. It is expected that the area under soybean will increase through time, eventually replacing sunflower as a double cropping activity.

Table 2.4 shows a great variability in crop yields through time.

Corn yields for the 1935-1962 period shown in Figure 2 seem to indicate a positive trend since the early 60's. During this period hybrid corn[1] and 2,4-D herbicide were being adopted by the farmers and a rapid process of mechanization was taking place in the area. More effective weed control and the replacement of open pollinated varieties could explain the fact that the troughs are at higher yields than they were before. Favorable weather conditions also seem to explain the positive trend.

During the 1970/71 corn growing period, rainfall was well above the average for the area explaining the high corn yield shown in Figure 2. The opposite happened during the 1971/72 period; rainfall during January (grain filling stage) was 2.7 inches (68 mm) below the 4.36 average (109 mm) for Casilda. Average rainfall before and during flowering time corresponded to the averages for the area.

Wheat yields presented in Figure 3 do not seem to show

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[1]Martinez reports a 50 percent adoption of hybrids in south Sante Fe province by 1961 (31).

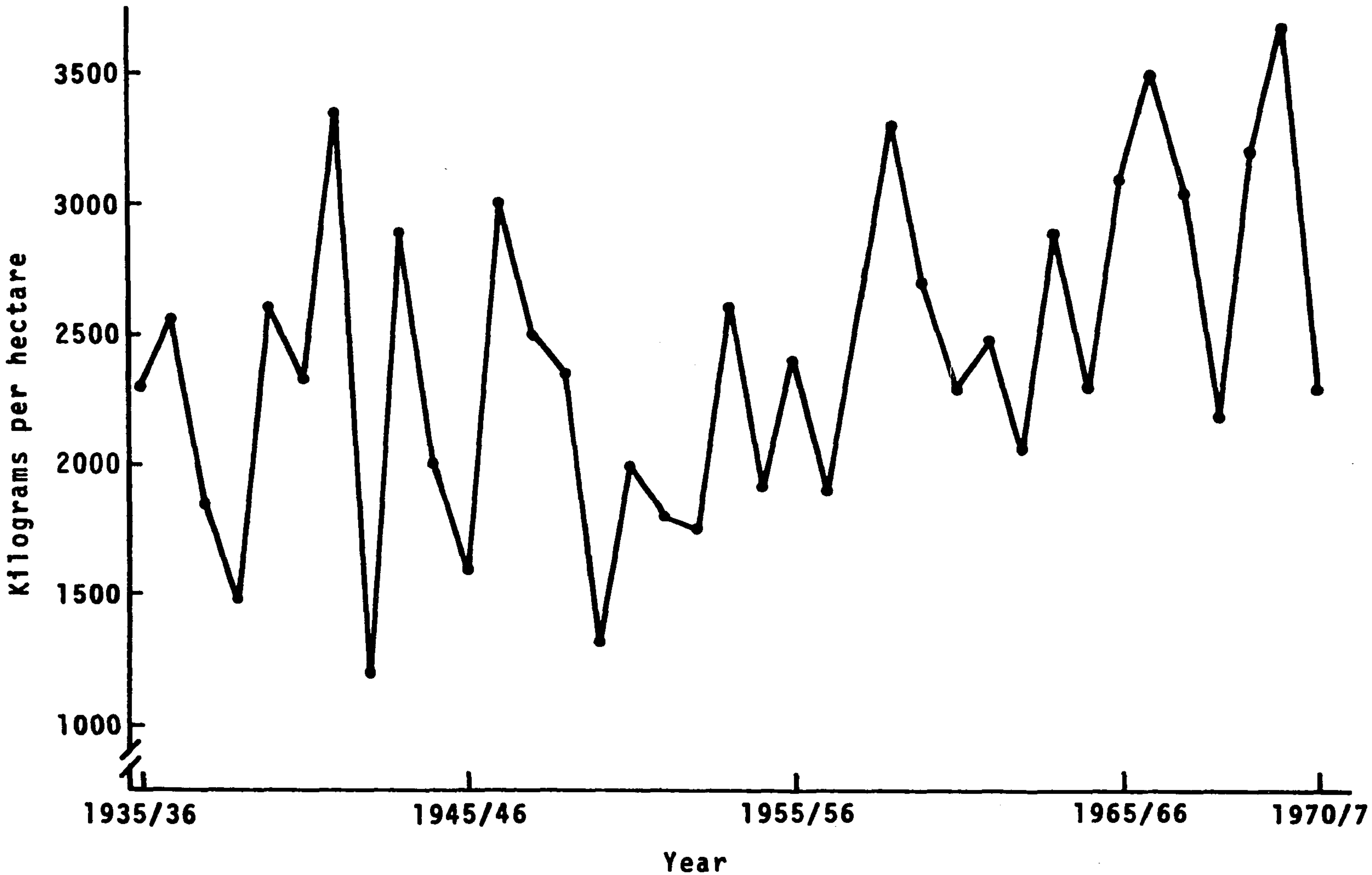

Figure 2. Corn yields for Caseros county during the 1935-1972 period

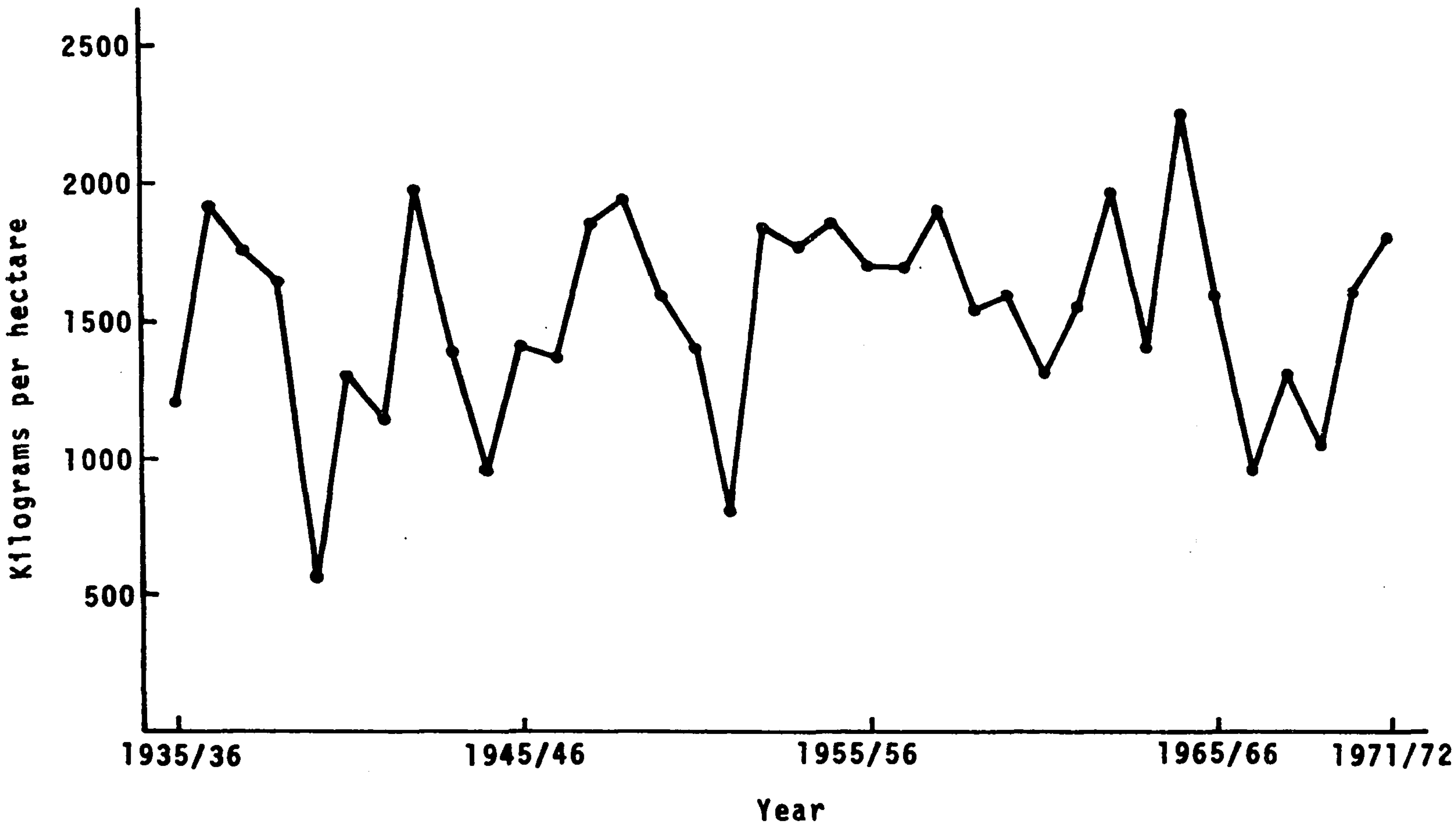

Figure 3. Wheat yields for Caseros county during the 1935-1971 period

any trend during the 1935-1971 period, they also show great variability during that period.

Survey Data

A stratified random sample[1] by farm size was drawn from a list of corn producers[2] in Caseros county.

The questionnaire was designed to obtain information about area planted under different crops, number of cattle, area under permanent pastures,[3] and total production obtained for the different activities carried out during the 1971-1972 period. The data collected provided information about the number of years without pastures and crop rotations during the last three years for each field under corn during the study period. The corn yield obtained during the previous season characterized by favorable weather conditions was also requested. The information was collected by INTA agronomists during the March-May 1972 period.

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[1]The Neyman-Pearson method was used to determine sample size within each strata.

[2]The list was based on the National 1969 Census.

[3]Permanent pastures consist of a mixture of grasses and legumes including alfalfa.

<u>Sample size</u>

Table 2.5 shows the number of farms in each of the strata composing the sample.

The actual number of survey questionnaires that could be completed was 90. The actual size and composition of the sample did not differ much from the ideal ones dictated by the sampling design. Farms below ten hectares were considered as noncommercial corn producers and were not included in the population.

Table 2.5. Composition of the survey sample[a]

Farm Size Hectares	No. of Farms Producing Corn in 1969[b]	Sample Size	No. of Surveys Completed
10-30	239	10	8
30-60	782	23	23
60-120	1000	31	28
120-250	461	16	16
250-400	87	9	8
+400	54	7	7
Total	2623	96	90

[a]Source: data from Censo Agropecuario Nacional 1969 and survey sample design.

[b]1969 census data have not been published yet.

Land use

Division points between classes in Table 2.6 are somewhat arbitrary. Aggregation was done after careful consideration of some of the variables which could affect soil fertility. This division will be maintained throughout this study and we will be referring in the text to farms in groups 1, 2 and 3, respectively.

The proportion of total land devoted to specific uses in each sample group is depicted by Table 2.6. This table shows that the two dominant crops in the area are corn and wheat. Farms below 120 hectares used more than 50 percent of their land for corn production. Approximately 50 percent of the area planted under corn in the Department of Caseros corresponds to farms of 120 has or less, according to 1969 census data.

Table 2.6 shows that farmers in group 1 and 3 proportionally devote less land to wheat than farmers in group 2. Also the proportion of area under pastures in group 2 is less than in the other two groups. Analysis of the survey data also shows that group 2 devotes 16 percent of the land to double cropping activities. Double cropping seems not to be as intensive in farms in groups 1 and 3. They devote 10 and 5 percent of their land, respectively, to double cropping.

Table 2.6. Comparison of the percentage distribution of land use by farm size[a]

Crops and Pasture	Farm Size in Hectares		
	10-60	61-120	121 or More
Corn	57.9	50.6	41.3
Wheat	15.5	24.5	18.6
Other crops	3.5	1.1	.9
Total crops	76.9	76.2	60.8
Alfalfa	3.0	4.4	9.9
Permanent pastures	14.4	12.9	20.5
Annual pastures	2.4	1.0	3.9
Range land	.3	.1	2.4
Total pastures	20.1	18.4	36.7
Hog facilities, house and roads[b]	3.0	5.4	2.5
Total	100	100	100

[a]Source: derived from survey data.

[b]Estimated as a residual.

Average corn and wheat yields

The average yields computed from the total production reported by the farmers show no significant differences for wheat for the three groups, but differences do exist in corn yields.

In Table 2.7 the average corn yields reported by the farmers for the previous year are presented. This information was also requested because during the 1970-1971 corn

Table 2.7. Statistics of crop yields and percentage of farms growing the crops[a]

Statistic	Group 1			Group 2			Group 3		
	Corn 1971/72	Corn[b] 1970/71	Wheat 1971/72	Corn[c] 1971/72	Corn[b] 1970/71	Wheat 1971/72	Corn 1971/72	Corn[b] 1970/71	Wheat 1971/72
Sample mean kq/ha	2510	3922	1570	2100	4259	1637	2602	4529	1552
Sample standard deviation	7.9	11.92	3.92	9.03	9.49	4.35	10.13	11.31	5.46
Coefficient of variation	28	30	25	43	22	26	38	25	35
Percentage of farmers	100.		64.51	100.		75.	100.		83.8

[a]Source: derived from survey data.

[b]Four, six and seven observations were missing in groups 1, 2 and 3, respectively.

[c]One observation with zero yield because hail damage was dropped from the analysis.

growing season conditions were exceptionally favorable in terms of rainfall.

The average corn yield obtained from the survey[1] is approximately 5 percent above the average[2] estimated by the Ministerio de Agricultura for Caserios county for the same period, and is below the 1960-1970 average of 2757 kg/ha harvested.

The average corn yield for group 2 was below the average for the county and quite far below the average with respect to the other two groups during the 1971-1972 period.[3]

During the 1970-1971 period, under favorable weather conditions, differences among groups tend to decline, corresponding to the higher corn yield for farms in group 3. This group devotes 36.7 percent of their land to pastures compared to 20.1 and 18.4 percent for groups 1 and 2 respectively.

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[1]Estimated population mean is $\bar{y} = \Sigma \frac{n_h \bar{y}_h}{n}$ where n_h = size of the strata $n = \Sigma n_h$ and $\bar{y}_h$ = sample mean in the strata. The estimated population mean is equal to 2418 kg/ha harvested during the period 1971-1972.

[2]The estimated average for 1971-1972 was presented in Table 2.4 and was 2300 kg/ha harvested.

[3]A t test of differences between means show significant differences in corn yields between group 1 versus 2, and between groups 2 and 3. Differences in mean corn yields between groups 1 and 3 were not significant.

Proportion of area under pasture by farm size

Figure 4 shows the percentage of area under pasture for the three groups of farms. Group 1 and 2 have a common mode representing farms with approximately 10 percent of the total area under pasture. A chi-square test shows that the distribution for groups 1 and 2 are not significantly different.

Group 3 presents a different mode and the chi-square test shows that the difference in distribution with respect to the other two groups seems not to have arisen by chance. The chi-square test was significant at a level of .05. The percentage of area devoted to pastures seems to be dependent on farm size.

In the next section the relation between area under pasture and corn yields will be analyzed.

Relation between area under pasture and corn yields

Figure 5 seems to show a positive relation between area under pasture and average corn yields. This relation is obscured by some other factors.

Figure 5 shows a positive relation between area under pastures and average corn yields. A rigorous test of this relation will have to take into consideration other factors that also influence yields. Average yields, assuming weather conditions are the same, will depend on the level of

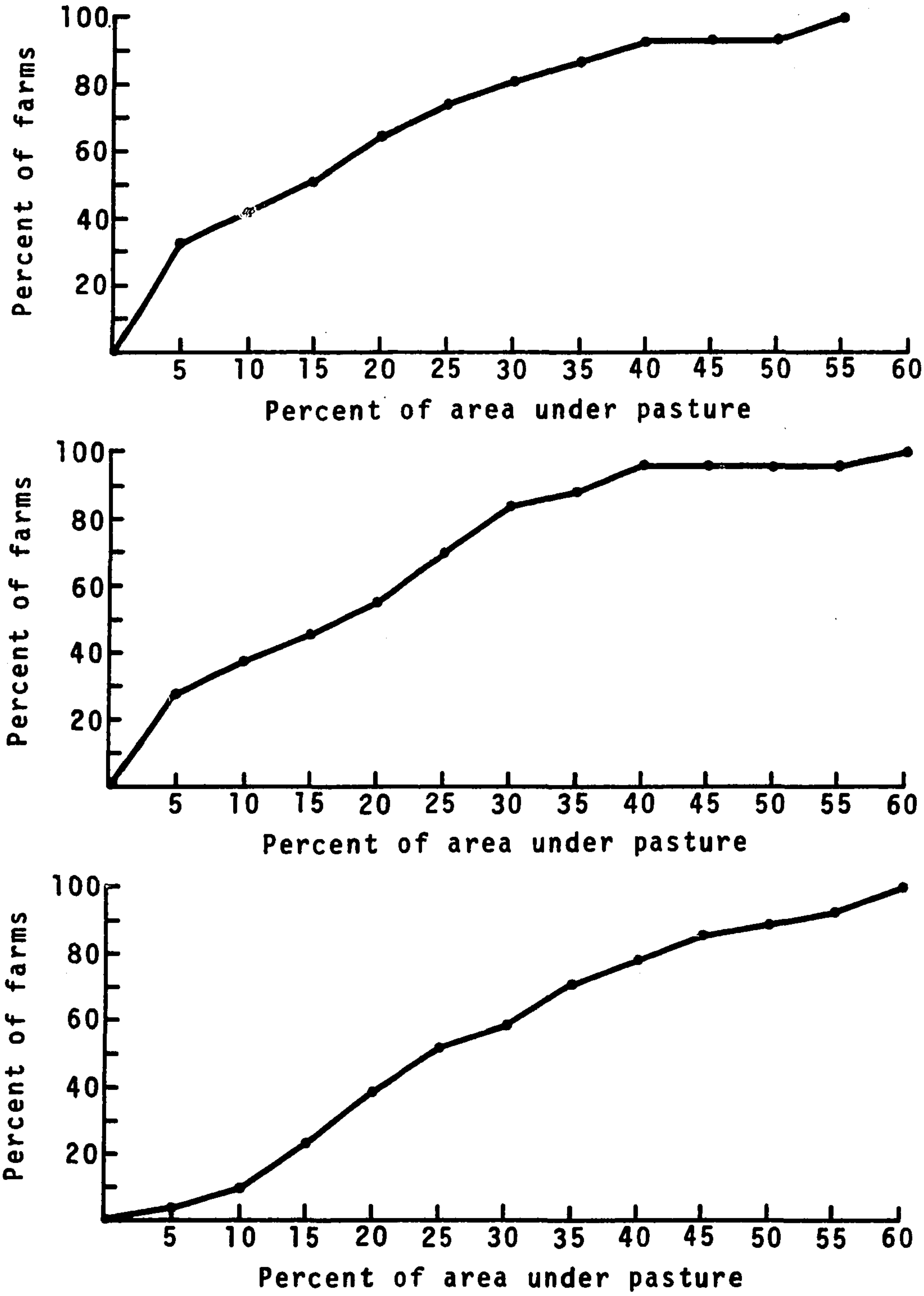

Figure 4. Cumulative frequency distribution of area under pasture per farm group

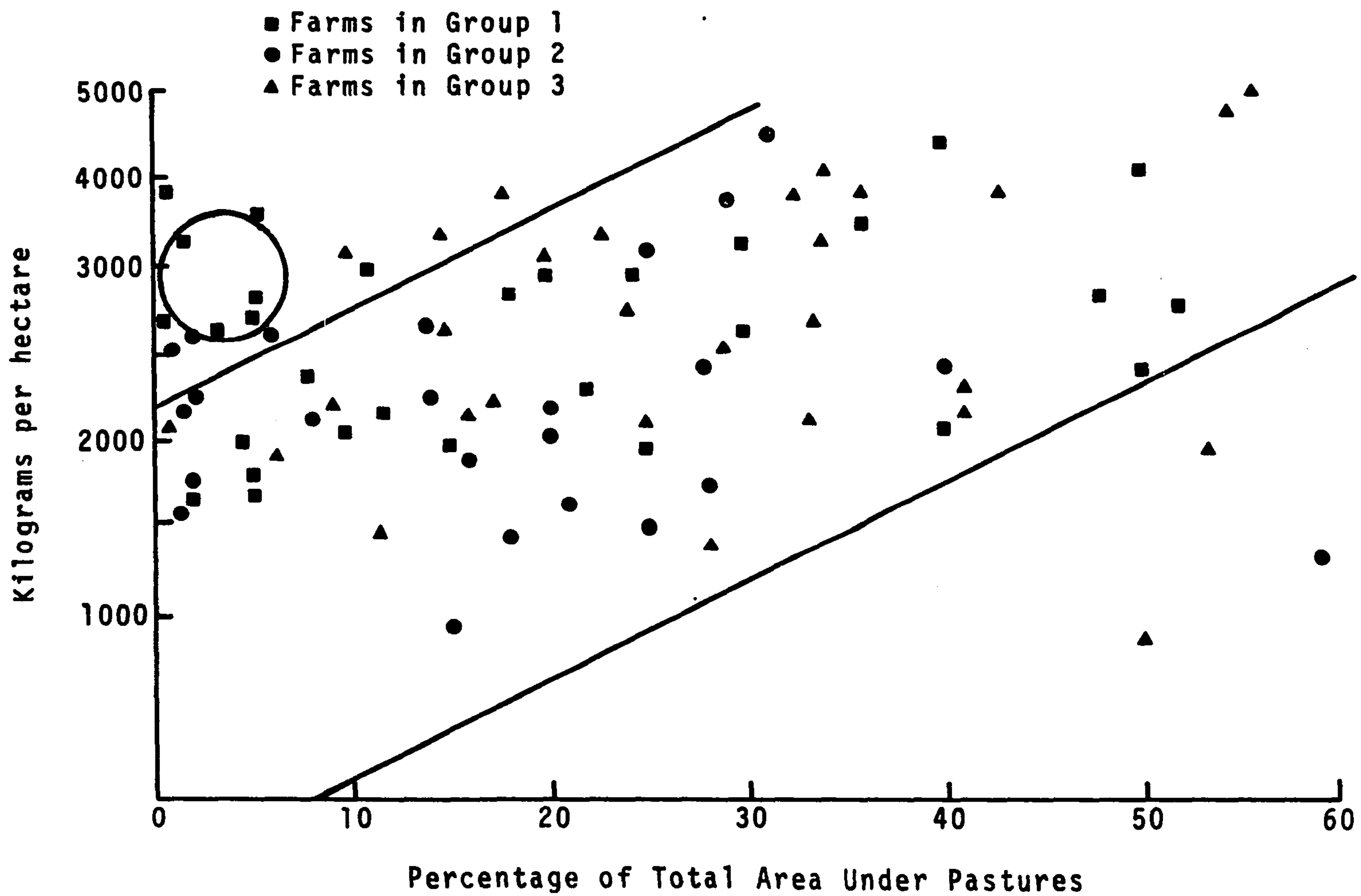

Figure 5. Relation between area under pastures and corn yields

use of other factors, previous rotations and management.

The circled area in Figure 5 includes a group of farms with a low proportion of land under pasture and a relatively high corn yield. Looking at the previous rotations per field, survey data shows that the corn fields have been under pastures during the last two or three years or under wheat before planting corn. By including wheat in the rotation before planting corn, land is fallow for a period of seven months. During this period subsoil moisture and soil fertility levels are partially restored. This in part could explain the relatively high yield of this group of farms.

Rotation pattern in the area

Looking at the rotation pattern in this area, survey information shows a certain relation between number of years without pastures and the inclusion of wheat in rotation with corn.

The number of fields presented in Table 2.8 corresponds to fields that have been under corn during the 1971-1972 period.

Table 2.8 indicates that the proportion of fields that have been under wheat, at least once during the last three years, becomes larger as the number of years without pastures increases. It seems that by this type of rotation farmers are able to restore soil productivity levels enough to introduce

Table 2.8. Proportion of fields with wheat-corn rotation pattern[a]

Years Without Pastures	Number of Fields with Continuous Corn[b]	Number of Fields with Wheat-Corn $n_{i.}$ [c]	Total $n_{i.}$ [d]	Proportion $P_i = \frac{n_{i1}}{n_{i.}}$ %
5 or less	74	10	84	11.90
6-10	16	15	31	48.38
11-15	10	14	24	58.38
16-20	5	3	8	37.50
Total	105	42	147	

[a]Source: derived from survey data.

[b]Fields that have been under corn during the last three years.

[c]Fields that have been planted with wheat at least once during the last three years.

[d]Information based on 147 fields corresponding to 82 farms. For some fields the information was incomplete and was not considered in the analysis.

corn again into the rotation.

From Table 2.8 it can also be seen that approximately 43 percent of the corn has been planted on fields that have not been under pasture for 6 or more years.[1] This is more evident in farms included in group 2. Fifty percent of the area planted with corn during the 1971-1972 period was on fields that have not been under pastures for more than 6 years compared with 23 percent in farms included in group 1.

Farms in group 2 on the average include legumes in their rotations every 8.5 years compared to 6.5 and 5.7 years for groups 1 and 3 respectively. It was shown in Table 2.6 that farms in group 2 have the lowest proportion of area under pastures; it was seen that during the 1971-1972 period corn yields were significantly lower than for the other two groups. It was also mentioned that this group devotes a larger proportion of their land to double cropping activities than the other two groups. In the next chapter information will be presented about seedbed preparation for different farm groups and a hypothesis will be formulated in order to try to explain the lower corn yields for farms in group 2.

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[1]The nature of the data does not allow one to extrapolate these results to the entire population. The number of fields considered in the analysis represent 90, 85 and 50 percent of the total area planted under corn for farms in groups 1, 2 and 3 respectively.

Livestock

Beef cattle activities are common among farms in group 3. Ninety percent of the farmers included in this group reported having beef and/or dairy cattle. Dairy and beef activities are carried out on a larger scale in large farms compared to hog activities which predominate on small farms.

With actual technology cattle operations are conducted under an extensive land system. Permanent pastures and natural grasses are used as main sources of feeding cattle. This allows large farms a better management of the soil, restoring soil fertility levels through rotations with pastures. At the same time crop activities, which occupy 60 percent of the land in farms included in group 3, provide roughage during the critical production periods of pastures. Cattle graze on corn and wheat fields after harvesting, allowing the farmers a better management of pastures and a larger contribution of nitrogen to the soil.

Labor per farm size

In farms below 120 hectares the amount of labor available was 1.5 men per year.[1] It is mostly family labor. Seventy-three percent of the farmers reported to live on

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[1] 1 man per year = 1 man for 300 days, 10 hours a day.

Table 2.9. Percentage of farmers devoted to livestock activities and average number of animal units per farm[a]

	Group 1		Group 2		Group 3	
	Farms %	Animal[b] Units	Farms %	Animal Units	Farms %	Animal Units
Dairy Cattle	26	10.68	14.2	21.87	32.25	142.7
Beef Cattle	26	16.62	57.1	36.6	80.6	168.4
Hogs (heads)[c]	77.4	134.	46.4	94.6	51.6	14.5

[a]Source: derived from survey data.

[b]1 cow = 1 A.U., heifers and steers = 0.8 A.U., less than two years old = 0.7 A.U., calves = 0.6, less than six months = 0.25 A.U., bulls = 1.3 A.U.

[c]Hogs are expressed in total number of head.

the farms and seventeen to live in a small town close to their farms. Ninety-three percent reported farming as the main activity.

Farms above 120 hectares had an average 3 man years of labor available. Hired labor was common especially in large farms with cattle production. Fifty-eight percent of of the farmers lived on the farm and 36 percent lived in a small town near the farm, and six percent in a large city. Eighty percent reported farming as a full time activity.

Machinery

The level of mechanization in the area is quite high. Harvesting is under the custom hired system. Fifteen percent of the farmers included in the sample have combines and were engaged in this type of activity.

The number of farmers not having any machinery at all and renting the services from other farmers in the area was less than 5 percent. In Table 2.10 part of the machinery available in the farm has been presented. The level of mechanization is quite high given the size of the farms, especially for those below 120 hectares. Machinery for land preparation and cultivation seems not to be a limiting factor.

Not all the farmers have sprayers. It is a common practice in the area to rent one for applying herbicide. The number of rotary hoes is also not very high and in the next chapter we will see that it is still an uncommon practice to use the rotary hoe on corn.

Sources of credit and payment practices

There are several sources of credit to which farmers resort in order to carry out their operations and investments. Cooperatives, federal and provincial banks are the main sources of credit in the area.

Table 2.10. Machinery type in percentage by farm size[a]

Item	Farm Size in Hectares 10-60	61-120	121 or more
Plow	100	100	116
Tandem disk	51	71	84
Disk harrow	26	21	39
Tooth spike harrow	100	100	100
Rotary hoe	10	32	61
Grain drill	39	68	77
Corn planter	68	117	113
Sprayer	16	46	65
Tractor	93[b]	117[c]	174[c]
Combine	6	7	32

[a]Source: derived from survey data.

[b]Mode 40-49 HP tractor.

[c]Mode 50-59 HP tractor.

Banks give credit for corn seedbed preparation[1] and up to 80 percent of seed value. Credit is also available for harvesting expenses. Loans are to be repaid in six months

[1]During the 1971-1972 period credit for seedbed preparation was 30 pesos per hectare. Cost estimations done for this study show that this amount represents 50 percent of the expenses in seedbed preparation and cultivation.

with an annual interest rate of 16 percent.

The Bank of the Nation, an official agency, has special plans at lower interest rates for soil conservation practices (4). These plans cover 80 percent of expenses for green manure, chemical fertilizer and fallow practices.[1] This bank constitutes a potential agent for technological change in the area. This will depend on the extent to which farmers make use of credit. At present the use of credit is not very high. Only 41 percent of the farmers included in the sample were using credit for planting corn. No need for credit was the most common reason given by farmers not using bank credit for producing corn.

Cooperatives also play a certain role as a source of credit. Eighty-seven percent of the farmers included in the sample[2] are members of cooperatives. Inputs such as herbicides and seeds are provided by the cooperative and charged on farmers' accounts. Seventy percent of the 90 farmers included in the sample reported marketing the total or part of their corn production through cooperatives.

Harvest expenses are paid in cash or within 30 days

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[1]Repayment of these loans is at six months and can be extended to one year.

[2]This estimation is based on 80 questionnaires. Survey collection data on this item were not finished by the time the information was given to the author.

after harvest.

Marketing

The largest percentage of corn produced in the area is marketed through cooperatives, a minor proportion being channeled through private dealers. Drying facilities were not mentioned by the farmers as a limiting factor. Coscia in INTA (22) estimated the ratio between drying capacity available and the average corn production for the Caseros county to be .78 in 1967.

More than 90 percent of the corn produced in the area is exported. Means of transportation and communication to Rosario and Buenos Aires docks are good. The most serious transportation problem mentioned by the farmers was the sometimes temporary closing of the Buenos Aires and Rosario docks due to the inability of port elevators to load ships or to the lack of capacity of port elevators.

Limiting Factors to Corn Fertilizer Response

Fertilizer experiments were carried out in different parts of the Pampean region as early as 1945. In 1962 fertilizer trials became part of the research conducted by the Pergamino experimental station.[1] Results of those

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[1]Pergamino experimental station is the main site of corn research in Argentina.

trials show that corn fertilizer-response was very low and many times negative. Based on those results research was oriented toward weather and soil profile conditions trying to explain such contradictory responses (50). It is mentioned that the presence of a heavy textural "B" horizon on the soil profile limits corn root penetration, making corn plants more dependent on rainfall and soil moisture available in "A" soil horizon than on stored subsoil moisture (48). The authors predicted the evapotranspiration rate for the Pergamino area for the period 1927-1958. For this estimation they used the Thornthwaite method and soil moisture available in "A" horizon. During the 31 year period considered there was 58 and 68 percent soil moisture deficit in "A" horizon for December (corn flowering time) and January. Probably the author overestimates evapotranspiration due to not considering a correction factor for crop development and moisture stress (45).

Zaffanella (52, p. 31) and Andersen determined a minimum amount of rainfall during the period December-January of 200 mm in order to obtain response to fertilizer. Fagiolli in INTA (20) found that the critical period for corn in terms of rainfall in Argentina is between 15 and 20 days after flowering period, and that droughts in other periods of the cycle have a minor influence on yield.

Researchers in the U.S. (12, 44) have determined the effects of drought during different corn growing stages. The most critical period is during the pollen silk stage, depletion of soil moisture to the wilting point for six to eight days during this period could reduce corn yields by 50 percent. Denmead and Shaw (12) also report reductions of 25 and 21 percent in yield when the corn plant is subject to stress 30 days before and after the pollen silk stage respectively.

Effect of weather variables on corn yields in Caseros county

In order to study the influence of weather on corn yields, weather data and yields for Caseros county were analyzed for the 1935-1962 period. The weather variables included in the analysis were: total average rainfall from March to August and monthly average rainfall and temperatures from September to January.[1] Each weather variable was introduced linearly and quadratically in the multiple regression equation.

From Table 2.11 we see that for every degree centigrade increase in temperature in October[2] corn yield will

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[1]Rainfall and temperatures are expressed in mm and degrees centigrade.

[2]Mean values for the variables included in the equation are: yield = 2254.0, TO = 16.39, RN = 102.50, RN^2 = 13074.57, R x T = 2020.97, RD = 97.03, RD^2 = 16900.90, TJ = 23.58.

Table 2.11. Regression coefficients of weather variables on corn yields in Caseros county[a]

	Yield Kilograms per Hectare	"t" Values
Constant term	2610.93*	(1.47)
Temperature October	143.16****	(2.95)
Rainfall November RN	42.84****	(2.80)
Rainfall November RN^2	-0.048**	(-1.69)
Rainfall Temperature November R x T	-1.41***	(-2.26)
Rainfall December RD	4.94***	(2.03)
Rainfall December RD^2	-0.0126***	(-2.12)
Temperature January TJ	-163.88****	(-2.57)
R^2	0.68	

[a]Source: corn yield data from Ministerio de Agricultura y Ganaderia. Weather information from Servico Meteorologico Nacional.

*Significant at 15 percent.

**Significant at 10 percent.

***Significant at 5 percent.

****Significant at 1 percent.

increase by 143.16 kilograms per hectare.[1] In January for every degree increase in centigrade the mean corn yield will decrease by 163.88 kilograms per hectare. During January corn fields are in the kernel filling stage in Caseros county. It seems that temperatures above the mean during this period have a strong influence on corn yields. During the period analyzed, temperatures varied with respect to the mean from -2.18 to 2.82 in January compared to December[2] when the temperatures varied from -2.32 to 2.70. It seems that high temperatures in January are more damaging than in December.

These results also show that rainfall above the mean in November, keeping the other variables constant at their respective means, will have a larger effect on yield than an additional mm of rainfall in December. Rainfall in November presented lower variability than December during the 1935-1962 period[3] analyzed.

de Janvry (9) estimated the cumulative distribution of

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[1]The frequency of days with frost in October for Casilda is 0.4 (33, p. 144).

[2]Mean temperature for December was 22.32 degrees centigrade for the 1935-1962 period analyzed.

[3]The coefficients of variation for November, December and January rainfall are:
$C.V._N = \frac{51.50}{102.50} = .50$, $C.V._D = \frac{88.10}{97.03} = .90$, $C.V._J = \frac{83.00}{115.53} = .71$.

December rainfall for Casilda[1] using monthly rainfall reports from 1923 to 1969. His analysis shows that the probability of getting higher rainfall in December than 97.03 mm is approximately 40 percent. In a similar study for the Pergamino[2] area information about rainfall probabilities for every month in two and four week periods is presented (29). The probability of getting high rainfall precipitation during November increases by the end of the month. This could explain the higher value of the November rainfall coefficient, in Table 2.11, with respect to December. The same situation prevails during December--the probability of higher rainfall increases by the end of December coinciding with the critical corn pollen silking stage.

It seems that even though average rainfall in November is higher than in December during the period analyzed, uneven rainfall distribution during November affects corn yields more than in December. The significant interaction between rainfall and temperature in November shows that the effect of both factors are not independent. The effect of November rainfall on corn yield will depend on the magnitude of the November temperature. The higher the temperature the

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[1]Mean December rainfall in the de Janvry (9) study is 93.36 compared to 97.03 during the 1935-1962 considered in this study.

[2]This information is used because of the lack of a similar study for Caseros county. These two areas present slight differences in terms of average rainfall during the corn growing season (33).

lower the effect of November rainfall on corn yields.

These preliminary results seem to indicate that corn fields in Caseros county are more subject to stress before than during the pollen-silk stage. After the pollen-silk state high temperatures in January, during the dough and dent state, seem to affect corn yields more than rainfall.

The correlation coefficient between temperature and rainfall in January was r = -0.55, significant at the 2 percent level.[1] The partial correlation coefficient between corn yield and January rainfall holding January temperatures constant (15) was $r_{yj.t} = 0.07$ which is not statistically significant. It seems that during the 1935-1960 period analyzed, January rainfall, after eliminating the effect of temperatures, has a very low correlation with corn yields and the positive simple correlation between corn yields and January rainfall is because of the negative common association between rainfall and temperature (48). The partial correlation between corn yield and temperature in January holding rainfall constant was -0.41, significant at the 5 percent level.

It appears that high temperatures in January affect corn yields more than rainfall. The size of the coefficient

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[1]The correlation coefficient between rainfall and temperature with yield were r = 0.33 and r = -0.51, respectively, significant at 7 percent and 1 percent respectively.

in Table 2.11 shows the importance of January temperature.

Studies in the U.S. indicate that high temperatures are probably among the more important of the climatic factors that adversely affect corn yields, even when there is ample moisture in the soil (5, 47).

In a similar study,[1] Thompson (50) concluded that the best corn growing weather in Iowa would be above average temperatures in June and July, below average temperature in August, lower than average rainfall in June and higher than average rainfall in July and August.

A comparison of the average weather conditions for Iowa and Casilda is presented in Table 2.12.

A rigorous comparison between both groups of data can be questionable. There are other weather factors such as wind, atmospheric humidity and other factors[2] that could influence the degree of stress on the corn plant and should be taken into consideration.

The data presented in Table 2.12 present certain similarities in terms of rainfall between the two regions with higher mean rainfall during the silk emerging and dent corn

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[1]Thompson (50) analyzed the effect of monthly average temperatures and rainfall on corn yields for five states in the U.S. using multiple regression analysis.

[2]Preseason rainfall could affect available subsoil moisture. This variable was included in the analysis and resulted nonsignificant.

Table 2.12. Corn growing stages and average weather conditions for Iowa and Casilda[a]

Month		Corn	Rainfall in mm		Temperatures		
Casilda	Iowa	Stage	Casilda	Iowa	Casilda	Iowa	
					°C	°C	F
Nov.	June	Before silking	102.5	121.2	19.66	21.2	70.3
Dec.	July	Silk emerging[b]	97.03	88.7	22.32	24.	75.2
Jan.	Aug.	Dent stage	115.53	95.5	23.58	22.9	73.2

[a]Source: mean values for Iowa during the period 1930-1962 (50, p. 58) and mean values for estimated regression equation presented in Table 2.11.

[b]In Casilda silk emerging takes place between the first and second week of December.

stage for Casilda. Temperatures meanwhile are lower in Casilda except during the dent stage.

While weather conditions seem to affect the corn plant in the same way[1] and good and regular weather conditions alternate every so many years in both countries, corn yields have increased constantly through the years in the U.S.

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[1]Thompson's study shows that higher than average rainfall during July and August will increase corn yields in Iowa (50).

During the period 1930-1962 analyzed by Thompson (50), corn yield doubled in the cornbelt. Corn yield trends were level from 1890 to 1930 and started to climb after 1930 due to the adoption of hybrid corn. After the replacement of open-pollinated varieties by hybrids in Iowa in 1944, other technological changes have taken place. These changes have included further improvements in hybrids, an increase in plant density, increased use of nitrogen fertilizer, and more effective control of weeds and insect pests.

Table 2.13 shows that variation between years exists as it existed in the early 30's, but the troughs in the 60's are at higher yields than the peaks of the 30's. We could infer from this that even under similar unfavorable weather conditions yields will be higher today than they were in the 30's.

Meanwhile, corn yields in Caseros county have not increased at all. A time trend was included for the 1935-1962 period considered in the analysis. The regression coefficient was negative but not significant. Similar results were obtained by Reca (42) for Santa Fe province. Reca found no significant change in corn yields during the 1924-1965 period.

Corn yields in Caseros county present variability according to weather conditions, but it seems that the effect of weather on corn yields and its effect on the

Table 2.13. Maize production in Iowa, the adoption of hybrids and related changes in management practices[a]

Year	Area (000 ac)	Output (000 bushels)	Yield/ac (bu.)	Percent hybrid	Fert. N (lb/ac)	Area treated for corn borer (000 ac)	Area treated for soil insect complex (000 ac)
1930	11,335	385,390	34.0		0.08		
1931	11,732	385,983	32.9		0.08		
1932	11,849	509,507	43.0		0.03		
1933	11,375	455,000	40.0	0.7	0.01		
1934	8,986	195,895	21.8	2.1	0.01		
1935	9,826	373,388	38.0	6.0	0.01		
1936	10.759	190,434	17.7	14.4	0.02		
1937	11,082	498,690	45.0	30.7	0.03		
1938	10,417	479,182	46.0	51.9	0.03		
1939	9,506	494,312	52.0	73.4	0.04		
1940	9,024	473,760	52.5	90.3	0.06		
1941	9,069	462,519	51.0	96.9	0.08		
1942	9,568	574,080	60.0	98.9	0.10		
1943	10,716	605,454	56.5	99.5	0.22		
1944	11,037	579,442	52.5	99.8	0.24		

[a]Source: factors affecting the adoption of hybrid maize in the United States and Kenya. G. F. Sprague. Change in Agriculture, edited by A. H. Bunting (49, p. 89).

Table 2.13 (Continued)

Year	Area (000 ac)	Output (000 bushels)	Yield/ac (bu.)	Percent hybrid	Fert. N (lb/ac)	Area treated for corn borer (000 ac)	Area treated for soil insect complex (000 ac)
1945	10,706	476,417	44.5	99.9	0.56		
1946	11,134	634,638	57.0	100.0	1.29	20	
1947	10,410	317,505	30.5		2.20	100	
1948	11,191	677,056	60.5		3.00	800	
1949	11,471	550,608	48.0		2.40	1,750	
1950	9,798	475,203	48.5		4.14	150	
1951	10,190	443,265	43.5		5.65		25
1952	10,750	671,875	62.5		8.30	20	125
1953	11,180	592,540	53.0		13.61	590	200
1954	10,453	569,688	54.5		13.33	900	1,244
1955	10,767	522,200	48.5		8.16	700	1,000
1956	10,067	533,551	53.0		10.03	860	1,670
1957	10,218	633,516	62.0		12.79	1,218	2,200
1958	10,065	664,290	66.0		18.63	77	3,142
1959	12,481	811,265	65.0		16.52	72	5,413
1960	12,166	772,541	63.5		22.00	3	5,000
1961	9,976	753,188	75.5		32.95	168	4,000
1962	9,776	752,752	77.0		47.00	100	4,000
1963	10,656	868,464	81.1		51.27	150	4,000
1964	9,804	774,516	79.0		65.19	100	4,000
1965	9,933	814,560	82.0		82.14	200	4,000
1966						3,000	4,000
1967							

response to fertilizer has been overemphasized.

Results of the analysis presented in Table 2.11 and certain similarities with Iowa conditions seem to indicate that Argentine hybrids are less efficient, under farm conditions, in transforming rainfall into yield. This may be a combination of factors such as genetic material, weed competition,[1] soil insects affecting the root system, soil fertility levels, insects and diseases among others. Further agronomical research on these aspects is needed.[2]

In the next section two other factors mentioned as limiting corn response to fertilizer will be discussed.

Soil profile and organic matter

The presence of a textural B horizon[3] limiting corn root penetration has been mentioned in the literature as a limiting factor to fertilizer response (52). Therefore, corn planted in soils with a degraded A horizon will be very sensitive to summer droughts.

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[1]In Chapter III actual cultivation practices and seedbed preparation followed by the farmers in Caseros county will be discussed.

[2]Under the INTA-INRA program (30) started in 1969, the relation between corn plant, soil and weather conditions, and their influence on plant growth is being studied.

[3]The B horizon in some parts of the Argentine corn belt has a height which varies between 50 to 80 cms.

Other studies about root penetration show that corn roots penetrate the B horizon and go deeper than that absorbing subsoil moisture (20, 38).

In terms of organic matter, limits have been mentioned in which there will not be response to fertilizer (9, 11, 52). Zaffanella (52) mentions a minimum level above which the response to fertilizer will be very low. This minimum level was established at 5.7 percent as a result of adding organic matter content in the range of 0-20 and 20-40 cms of soil depth.

Results from the INTA-CIMMYT-FF[1] experiments on fertilizer show response to fertilizer on fields with organic matter of 3.4 percent or above. The first group of experiments carried out in 1968-1969 shows that there was significant response to nitrogen fertilizer on fields with 3.4 percent of organic matter when they were not under pasture for periods of more than 10 years (26). When the level of organic matter was above 4 percent and there was no response to nitrogen fertilizer, either the fields were without pasture for periods no longer than five years or hail storms and root damage by cultivation was reported as factors affecting the experimental results.

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[1]In 1968 a cooperative program between INTA-CIMMYT-FF to improve corn and wheat yields was started in Argentina.

The experiments carried out under the same program in 1969-1970 (25) show significant response to chemical fertilizer in fields with 4 and 5 percent of organic matter.[1] No information with respect to years without pastures for each experimental site was available when this data was collected.

de Janvry using data from experiments carried out by Marcos Juarez experimental station (9) and INTA-CIMMYT-FF 1968-1969 (11) experiments estimates fertilizer-response functions for corn. The author being interested in the substitutability of fertilizer for organic matter, specifies a Cobb-Douglas production function with an elasticity of production of fertilizer that is variable and a function of the level of organic matter. Organic matter is used as a proxy for actual soil fertility level. The interaction of organic matter by fertilizer turns up being negative and significant for both sets of data. This is interpreted as, the higher the actual soil fertility level the lower the response to fertilizer. The authors conclude that on soils with organic matter levels above 3.5 percent the response to fertilizer will be very low.

This hypothesis using data from INTA-CIMMYT-FF 1969-1970

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[1] Organic matter information was provided by E. Gonzales in charge of INTA-CIMMYT-FF fertilizer trials. Pergamino Experimental Station, INTA. Personal communication. 1972.

experiments was tested, where significant fertilizer-response on fields with organic matter up to 5.2 percent existed.

The same Cobb-Douglas functional form was used. Organic matter and the interaction with nitrogen fertilizer ended up being significant and with the expected signs but the plant population coefficient was negative.[1] Lack of information on other variables that could have affected the results did not allow further investigation of this data. Even though it is reasonable to expect lower fertilizer-response the higher the soil fertility level, organic matter as a proxy for actual soil fertility level involves several other factors. High levels of organic matter could mean better soil structure improving rainfall infiltration and soil aeration and then the rate of release of nitrogen to the plant. In soils subject to several years of continuous cropping, without including pastures in the rotation, even though they have high levels of organic matter, available nitrogen could be very low and show response to fertilizer.[2]

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[1]This means that the higher the plant population the lower the response to nitrogen fertilizer. This does not make sense especially for the range of variation presented by plant population during the period analyzed. Plant population varied from 38 to 60 thousand plants per hectare.

[2]R. D. Voss. Iowa State University. Personal communication. 1972.

This seems to be the case in the 1969-1970 INTA-CIMMYT-FF experiments.

The relation between organic matter and available nitrogen seems not to be very clear at this point. Further investigation along this line is needed. Information about previous rotations and number of years without pastures could provide information for a better interpretation of the experimental results. Results from 1969-1970 experiments indicate that the fertilizer frontier could be above the 3.5 percent organic matter level depending upon previous management of the soil.

CHAPTER III. PRODUCTION PRACTICES AND FERTILIZER RESPONSE

In pursuing the objectives of this research, certain biological factors that have been mentioned as limiting nitrogen fertilization to achieve its full potential were presented in Chapter II.

In this chapter reference to research in terms of production practices that have been successful under experimental conditions will be compared to what farmers are actually doing.

Most of the literature about corn in Argentina centers on rotations with pastures, green manure and proper timing of operations as means to increasing corn yields.

It will be shown from survey data that farmers are doing what experiments have shown to be the best practices.

In Chapter IV a programming model will be used to show that even though farmers know what is agronomically sound, in terms of short rotations with pastures, they have a different behavior that can be explained through economic variables.

Results of fertilizer-response functions estimated for Argentina compared to the U.S. will also be presented in this chapter.

Survey Information

The questionnaire included specific questions about practices followed on corn seedbed preparation and timing of cultivation. It was designed for the purpose of detecting the timing of the corn growing stage when tillage practices were carried out. Information with respect to presence of plow pan[1] and soil physical conditions was also requested.

Planting period and plant density

Factors such as optimum planting period and plant population have been studied for the Pergamino area (7). During the 1961-1965 period when the experiments were carried out, planting between the second and third week of September resulted in maximum yields compared to other periods.

One hundred percent of the farmers included in the sample finished planting corn in September.[2] The percentage distribution per farm size and week is presented in Table 3.1.

Approximately 92 percent of the farmers had finished corn planting by the third week of September. Caseros

[1]Soil compaction found immediately below the plow depth and increased by excessive trips over the field.

[2]One hundred percent of the farmers reported that they planted hybrid seed.

Table 3.1. Planting period in Caseros county per farm size[a]

Farm Size	Week			Total
	1	2-3	4	%
1	12.9	74.2	12.9	100
2	32.1	60.7	7.2	100
3	45.1	54.7	0.2	100
Percentage per week	28.9	62.2	7.8	100

[a]Source: derived from survey data.

county is located farther north than Pergamino; thus average September temperatures are higher. This explains why corn is planted earlier than the optimum date considered for Pergamino. Farms in group 3 seem to start planting corn earlier, this in part is due to the fact that they plant larger areas and need more time to complete corn planting.

The average amount of seed planted per hectare for the total sample was 24 kq per hectare (21.3 lb/a). Farmers seemed to be using more seed than needed[1] to obtain the

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[1]Assuming an emergence rate of 80 percent and an average weight of 300 grams for every 1000 kernels planted, would result in 64,000 plants per hectare at planting time.

optimum 50 to 55 thousand plants per hectare (20-22 thousand pl./a) determined by Bokde (7). It will be shown later on in this chapter that farmers seem to discount plant losses due to tillage practices and soil insects by increasing the number of kilograms of seed planted per hectare.

Plant distribution and weed control

The effects of plant distribution and its effect on corn yield has been studied by Mattioli (21) and Mattioli and Luna (23) in INTA.

Modern corn planting machines[1] together with the increased use of the rotary hoe are major changes that have been taking place in corn production during the last five to eight years.

Survey information shows that the use of modern corn planting machines has become common in Caseros county. Seventy-three percent of the farmers in group 3 have new planting machines. Adoption has not been so rapid among small farmers. In group 1 and 2 only 39 percent reported to have modern planters. The high price of the machine,[2]

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[1]Corn planting machines currently produced in Argentina incorporate several changes that permit a better seed distribution

[2]The cost in 1971 ranged from 800 to 900 U.S. $'s.

the relatively low area planted with corn on these farms and the expected gain in yield by a better seed distribution, could explain the lower rate of adoption by small farmers.

Farmers in the area seem to be aware of the influence of plant distribution on corn yields. Eighty percent of the farmers included in the sample reported to select plate according to seed size and planting rate. This and the fact that 50 percent of the farmers use modern planters gives some appreciation of the importance given to plant density and distribution. Most of the farmers reported to be planting between 4 to 5 plants per meter, that is between 57 and 70 thousand plants per hectare.[1] This does not mean that farmers are getting the optimum plant distribution and plant population at harvesting time. Weed control methods followed by the farmers in the area reduce stand and affect plant distribution.

During the 1965-1968 period, Bokde (7) carried out experiments using different tillage practices to control weeds. The treatments consisted of mechanical, chemical and a combination of both procedures. A combination of mechanical and herbicide treatments proved to consistently give higher

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[1]Row spacing for corn is 28 inches in Argentina.

yields.[1] Treatments including "aporque" gave higher yields and favored a deeper root development compared to treatments which did not include "aporque". Lodging was about 60 to 80 percent at harvesting time in those treatments where cultivation was not used at all. Atrazin[2] was used at planting time controlling broad leaf weeds but not crabgrass. Crab-grass was partially controlled between rows by cultivation.[3]

Similar results were obtained with experiments carried out under the INTA-CIMMYT-FF program (27). A combination of mechanical and 2,4-D herbicide control gave the higher corn yields.

Survey information shows that farmers use tooth spike harrow immediately after planting and before the seedlings emerge in order to control weeds and to break the soil crust

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[1]The treatment consisted of tooth spike harrow after planting followed by cultivation, 2,4-D herbicide and deep cultivation (aporque) in that order. "Aporque" is carried out with the objective of covering small weeds with dirt within rows and providing more support to the corn plant.

[2]Atrazin is not used by farmers due to its high cost. Lack of properly designed experiments do not allow economic evaluation of its profitability.

[3]Continuous use of 2,4-D by farmers has resulted in a predominance of grasses on fields that have been under corn for several years. Experiments under the INTA-CIMMYT-FF program have shown that fields highly infested with crabgrass compete for nitrogen with the corn plant (25).

that forms after a rainfall. Ninety-nine percent of the farmers included in the sample follow this practice. A second application of harrow follows after seedlings emerge in order to control weeds at early stages of corn plant development. When the corn plant is high enough first cultivation is carried out followed by application of 2,4-D and "aporque". The total number of cultivations, including "aporque", varied between two and three. Seventy percent of the farmers cultivate twice and 29 percent three times. The actual method of weed control used by the farmers is the method that under experimental conditions ended up being the best.

One side effect of the actual system of weed control besides reducing plant population and distribution is severe root pruning if the cultivator is not properly controlled. Lyons and Luna in INTA (28) suggest changes in the five row planting and cultivating equipment, in order to avoid root damage.

Another serious effect is the excessive number of trips over the field. Every time that the soil is tilled, new weed seeds are brought to the surface where they find a fine seedbed to germinate, at the same time soil compaction between rows increases especially when tillage practices are carried out on wet fields. Soil compaction which limits root development, root pruning, soil moisture loss through cultivation of the soil and weed competition are factors that could contribute to the sensitivity of corn plants to stress.

Seedbed preparation

Survey information with respect to number of practices and type of machinery used before planting corn shows a very intensive seedbed preparation.[1]

Table 3.2 shows that small differences exist among farm sizes and rotations but it is indicative of the intensity of land preparation and number of trips over the field.

The nature of the data does not support final conclusions in terms of differences between groups, but shows consistency in a reduced number of practices when corn follows a pasture.

Farmers seem to carry out more operations on fields that have been under corn for the purpose of increasing rainfall infiltration, to control weeds during the winter, to improve soil aeration and to favor nitrogen release by a fine seedbed preparation.[2] This process seems to be more

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[1]This information was requested by type of rotation. Three categories were considered: corn following a summer crop (corn, sunflower or soybean), a winter crop (wheat) and a pasture. The information was incomplete in some questionnaires, so the data presented in Table 3.2 represents 90 percent of the sample for corn following a summer crop and 70 percent of the observations for corn following a pasture.

[2]During visits to the area farmers explained that that was the only way to obtain high corn yields.

Table 3.2. Average number of operations and type of machine used before planting corn[a]

Machine type	Farm Size					
	1		2		3	
	S.C.-C[b]	P.P.-C[c]	S.C.-C	P.P.-C	S.C.-C	P.P.-C
Plow	1.5	1.4	1.3	1.4	1.3	1.6
Disk	1.8	1.1	2.5	1.3	2.1	1.3
Harrow	3.2	2.5	3.7	2.3	2.8	2.5
Total	6.5	5.0	7.5	4.9	6.2	6.5

[a]Source: derived from survey data.
[b]Corn following summer crop.
[c]Corn following permanent pasture.

intensive in farms in group 2.

Considering the total number of operations before and after planting corn, we end up with a total of 12 to 13 trips over the field before corn reaches the pollen silk stage.

The number of operations and the fact that most of them are carried out during the rainy season could indicate a serious soil compaction in the area.[1]

Fifty percent of the farmers included in the sample reported presence of plow pan in their fields. Plow pan

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[1]Number of seedbed preparation operations were presented in Table 3.2, plus, planting, two times harrowing, two cultivations and 2,4-D application.

seems to be more common in farms of group 2. Sixty-four percent of the farms in this group have plow pan.[1] From Tables 2.6, 2.7 and 3.2, we find that this group proportionally has less area under pasture, lower corn yields and carried out a more intensive seedbed preparation. Group 2 on the average includes pastures in their rotations every 8.5 years compared to 6.5 and 5.7 years for group 1 and 3 respectively. Table 2.6 also shows that group two proportionally plants more wheat than the other two groups. Given the yields and wheat prices, wheat activity is less profitable than corn.[2] In Table 2.8 it was seen that proportionally wheat enters into the rotation more frequently after the fifth year of continuous corn. Through this type of management farmers allow a seven month fallow period during which soil fertility and subsoil moisture is partially restored enabling farmers to plant corn on those fields again.

All this seems to indicate that farms in group 2 have fields with lower fertility levels and soil compaction

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[1]Sometimes the presence of plow pan is difficult to detect. Ten percent of the farmers in this group reported not to know if their fields have plow pan or not and they were not included in estimating the percentage presented above.

[2]It will be seen in Chapter IV that by introducing wheat into the rotation farmers incur an income loss.

problems that make the corn plant more susceptible to stress. This could explain the lower corn yields for this group during the 1971-1972 period.

It is hypothesized here that soil compaction and low soil fertility levels could be major factors in poor root development and sensitivity of the corn plant to stress and lodging. Aldrich and Lang (2) report that well fertilized corn has a deeper and more extensive root system enabling the corn plant a better use of moisture. Pearson (39) mentions that soil compaction limits root growth, reduces soil pores reducing transmission of water and gases. When soil dries out soil strength increases sharply limiting root growth. The author also mentions that reduction in aeration reduces root growth and water uptake by concentration of carbon dioxide in the root zone.

Farmers in the area seem to be in a kind of vicious cycle. High prices of fertilizer and preemergence[1] herbicides lead them to follow tillage practices to restore soil fertility levels and control weeds that increase soil compaction, topsoil moisture loss, and root pruning, making the corn plant more sensitive to temporary summer droughts. By

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[1]The term preemergence herbicides is used to designate modern selective herbicides that can be also applied after planting.

intensive soil cultivation, soil structure[1] in the area has deteriorated seriously. Eighty percent of the farmers reported soil crust formation (planchado del suelo) after rainfall. This problem equally affects small and large farms.

The development of a new package of practices including preemergence herbicides and use of chemical fertilizer would reduce the number of seedbed and tillage practices. By using nitrogen fertilizer the amount of residues incorporated into the soil after harvesting is greater improving soil structure, rainfall infiltration and soil aeration. Further research is indicated along this line.

The need for "aporque" which results in severe root pruning may be reduced by the use of preemergence herbicides and the reduction of soil compaction conditions.

Nitrogen Fertilization and Hybrids' Response to Fertilizer

Since 1962, fertilizer experiments have been part of the research program of Pergamino experimental station and in Marcos Juarez since 1965. Reca (43) using 1967-1968 Marcos Juarez data[2] found that with the prevalent fertilizer-

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[1]Degree of aggregation of soil particles. Good soil structure improves soil drainage and aeration.

[2]Reca used a Cobb-Douglas function.

corn price relationship of ten and 60 thousand plants per hectare the optimum level of nitrogen fertilization was about 30 units per hectare. Using the same data and function, de Janvry (9) introduced an interaction term between organic matter and fertilizer. This interaction ends up being significant and with a negative sign. The higher the level of organic matter the lower the response to fertilizer. de Janvry and Koening (11) analyzed data from different experiments conducted by Pergamino and Marcos Juarez experimental stations. They found economic response in most of the experiments.[1] Peterson and Fienup (40) analyzed three-year experiments (1967-1970) using Marcos Juarez data. The authors conclude:

1. That plant populations which result in maximum yield are greater than 60 thousand plants per hectare.[2]
2. Organic matter coefficients were negative but none was significant.
3. The size and significance of the year dummies reflecting differences in overall growing conditions tend to decline at the higher levels of nitrogen

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[1] In those where response was not found, multicollinearity between variables existed.

[2] Novello and Puricelli (37) show that maximum response to fertilizer was obtained with populations between 60 to 65 thousand plants per hectare.

fertilizer. "From this result one might infer that nitrogen application reduces the variability of corn yields due to variation in growing conditions."[1]

INTA-CIMMYT-FF fertilizer experiments

The functions used by de Janvry and Reca present the characteristic that as the rate of fertilization increases a maximum corn yield is not defined (19), not allowing determination of maximum response to fertilizer under present conditions. Data from INTA-CIMMYT-FF experiments were analyzed for that purpose. The results of this analysis will be used in the programming model to determine maximum gains in corn yields that can be expected under present conditions.

Experiments carried out under this program on five locations[2] during the growing seasons of 1969-1970 and 1970-1971 were selected. A dummy variable for year was introduced in order to take into account differences in growing conditions between the two years. A quadratic production

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[1]Similar results are reported by Aldrich and Leng for the U.S. (2).

[2]The locations analyzed were O'Higgins and Moll in Buenos Aires province, and Peyrano, Elortondo and Villa Cañas in Santa Fe province.

function of the form

$$YD = A + SD + OM + R_i + N_j + N^2 + D$$

$$i=1,2,3$$

$$j=0,50,100,150$$

was used where:

YD: yield in kq per hectare

SD: number of plants per hectare

OM: organic matter in percentage[1]

R: rainfall for the period i in mm[2]

N: nitrogen levels in kilograms per hectare

D: year dummy.

Estimates for the parameters in the response function are presented in Table 3.3.

The year dummy, organic matter, the intercept, and rainfall before and after flowering coefficients turned out to be nonsignificant.[3]

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[1]Soil organic matter level varied from 2.4 to 5.2 percent.

[2]R_1 = rainfall 30 days before flowering, R_2 = rainfall during flowering and R_3 = rainfall 30 days after flowering.

[3]Rainfall before and after flowering varied from 14 to 174 mm and from 100 to 200 mm respectively for the different locations and years. Rainfall information was missing in one observation.

Table 3.3. Regression coefficients for the INTA-CIMMYT-FF experiments[a]

Dependent variable	Stand	Rainfall December 10-29	Nitrogen	N^2	R^2
Yield	.098***	6.424	20.255***	-0.102***	0.98
	(18.36)[b]	(2.69)	(3.38)	(2.68)	

[a]Source: data from INTA-CIMMYT-FF experiments. Data provided by E. Gonzales in charge of INTA-CIMMYT-FF experiments carried out by Pergamino experimental station, INTA.

[b]"t" values.

***Significant at 1 percent.

Table 3.4 shows response to fertilizer in Argentina using two different sets of experiments compared to a response to fertilizer in central Iowa under farm conditions (32).

Besides showing consistency in the response to fertilizer through the years and in different locations of region 1, the table also shows that under actual production practices and with available hybrids in Argentina, the response to nitrogen fertilizer above 60 kilograms of nitrogen per hectare is very low. Data from INTA-CIMMYT-FF experiments show that the maximum corn yield response to fertilizer

Table 3.4. Corn response to fertilizer in Argentina compared to the U.S.

Fertilizer in kg/ha	[a]	[b]	[c]
0	4,148	4,670	4,426
30	4,748	5,186	5,096
60	4,881	5,518	5,624
90	4,960	5,666	6,010
120		5,631	6,240
150			6,454
180			6,601

[a]Response under average weather conditions using de Janvry and Koening (11, p. 35) estimated function--Marcos Juarez data 1967-1968.

[b]Derived from fertilizer response function presented in Table 3.3.

[c]Response to fertilizer under average weather conditions at farm level in north central Iowa in 1964 (32, p. 19).

for this group of experiments is close to 100 kilograms of nitrogen per hectare.[1] The data from Iowa shows larger response to nitrogen fertilizer above 60 units of nitrogen

[1]Average plant population for this group of experiments was 44733 plants per hectare, and remained the same for different levels of fertilization. Experiments with higher plant population could give a different response.

and no maximum, even at 180 units per hectare.[1]

Fertilizer-response functions presented in Table 3.4 show a response comparable to the U.S. at levels of fertilization between 30 to 60 units of nitrogen per hectare. Assuming an average corn yield of 4000 kg/ha (63 bu/a) the corn plant will remove approximately 65 kilograms of nitrogen per hectare (56.7 lb/a).[2]

Given the average corn yields in Caseros county (2717 kg/ha), the amount of nitrogen removed from the soil will vary, depending on yield, between 50 to 65 kilograms per hectare. Considering that Argentine soils do not freeze during the winter, partial restoring of nitrogen levels could explain the low response above 60 units of nitrogen per hectare.

The development of highly fertilizer responsive hybrids, changes in production practices due to the introduction of preemergence herbicides and fertilizer will

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[1]Iowa data show increasing rates of phosphorous and potassium fertilization at higher levels of nitrogen. Experiments including phosphorous are being carried out under the INTA-CIMMYT-FF program. There seems to be some response, and experimentation along this line continues. Potassium seems not to be a limiting element for the time being in Argentine soils.

[2]One bushel of corn removes approximately 0.9 pounds of nitrogen (51).

remove factors that today seem to be limiting corn yields. Higher corn yields, desired to increase Argentine agricultural exports, will result in higher nitrogen removal from the soil and larger responses to nitrogen at high levels of fertilization.

Chapter V will discuss the effects of the development of highly responsive hybrids and changes in production practices on farm-level resource use patterns.

CHAPTER IV. THE MODEL AND INTERPRETATION OF THE RESULTS

This chapter will discuss optimum farm plans for a hypothetical farm[1] compared to actual farm plans in the area. Chapter V will show how optimum farm plans might be changed by the introduction of technology available today in Argentina. Experimental data on rotations including green manure and chemically fertilized corn will be used to introduce available technology into the model. Also, how optimum farm plans will be affected by the development of highly fertilizer-responsive hybrids and new production practices will be discussed.

The analytical technique used to measure the impact of the new technology already available in corn production and how it will affect farm plans is linear programming. Linear programming permits a simplified specification of a multi-product firm. This method of analysis insures optimum resource allocation among the alternative activities within the restrictions specified for the model. Assumptions and procedures for applications of linear programming are explained in several sources. Applications in agricultural

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[1]Two variants for the synthesized farm are considered: a farm with cattle activities (model 1) and a farm without cattle activities (model 2). It is expected that farms with cattle activities will present a different behavior toward the production technology available today in Argentina.

economics can be found in the book by Heady and Candler (18). Modified simplex solutions have been used in this study. Solutions were computed with varying prices to specify shifts in optimum resources. The procedures for the modified simplex solutions and construction of the model followed Beneke and Winterboer (6).

Optimal solutions were obtained through the use of the IBM 360 computer at Iowa State University, Ames, Iowa. The computer program used was MPSX/360-L.P. The input-output information is presented in the Appendix.

The Synthesized Farm

The farm analyzed in this study is assumed to have an area of 95 hectares. This farm size was selected because it represents the average size farm for the county (departamento) of Caseros. Farmers with farms between 60 and 120 hectares comprise the largest group in the county. According to the survey data the major differences in terms of activities by farm size were the presence of cattle activities and the area under permanent pasture. Farms below 120 hectares have few cows; 50 percent of them have no cows at all. Given the particular soil fertility problem of the farms in this group, the adoption of new corn technology is likely to be more beneficial to them than to farms of other sizes.

Due to the fact that the data were taken from various sources, the technological coefficients may not be entirely applicable to a particular farm. Differences in production techniques from farm to farm could result in different technological coefficients and optimum farm plans.

The data on seedbed preparation and cultivation practices on corn were derived from the survey conducted in the area. The survey also provided information about corn yields under different rotations followed by the farmers, labor available per year, payment practices, machinery size, and cattle inventory.

Labor requirements and machinery expenses in lubricants, parts and fuel-oil were derived using engineering estimates (41). Factor prices were obtained in the area of study and correspond to the September-November 1971 period. Grain prices used in the model were the support prices for the period 1971-1972.

Input-output information for crops other than corn was provided by the extension agent of INTA in the area.

Information with respect to the available technology was obtained through INTA publications and recommendations to farm demonstrators in the area (24). When some of the data were not available, knowledge obtained through visits to the farmers in the area and personal judgment were used.

Total digestible nutrients (TDN) requirements for cattle activities were based on tables prepared by the National Research Council (36). Prices for cattle activities considered in the model were average prices in the Rosario market for the year 1971.

Operating capital is defined as the amount of capital the farmer will demand during the period June-November. It is assumed that if operating capital is sufficient during the peak period of June-November, when most of the expenses to plant wheat and corn take place, it will not be limiting in other periods of the year.

In defining the capital restriction for model 1 it is assumed that the farm operator has 15,000 pesos in cash plus the value of feeder cattle.[1] In model 2, representing farms without cattle activities, it is assumed that the farmer has 5000 pesos in cash and borrows at a 16 percent annual rate of interest for six months.[2]

Operating capital as defined here does not include expenses for seeds and herbicides. Farmers charge these expenses to their cooperative accounts, which are then deducted

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[1]Feeder cattle is considered as if it were cash in hand. The survey does not provide information on the amount of cash available to carry on the plan.

[2]Restrictions on operating capital for both models and borrowing on model 2 are arbitrary assumptions. Information on cash available would have allowed more realistic restrictions on working capital.

from sales when they market production.

Total man labor days available to the farm per year was based on survey information. It consisted mainly of the operator's labor. Labor supply was grouped in units of two and three months to establish seasonal labor supplies.[1]

It was seen in Table 2.10 that the stock of machinery and tractors is more than enough, for this particular farm size, to carry on the plan.[2] It will be assumed that the stock of machinery is fixed and the services of machinery will not be limiting in any field operation.

Input-output price relationships will be maintained constant throughout this study except when specified. Variations in optimum plans under different fertilizer-corn and cattle-corn price relationships will be analyzed in the next chapter.

The optimum plans presented under different price and technology assumptions attempt to show changes that would occur in farm plans if farmers behave as if they were trying to maximize profits. These optimum plans represent static

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[1]Labor hours available for field work varied during the year. This is reflected in the labor restrictions introduced in the model. Also labor requirements not identifiable with any particular enterprise were deducted. The total number of labor hours available for field work was estimated in 2690 per man-year.

[2]Given the area planted under corn, corn planting machines seem not to affect proper timing of planting operations.

situations under conditions of perfect information. Risk and time elapsed in adopting the available and new technologies that will be discussed in Chapter V are not considered in the model.

It is also assumed in model 1 (with cattle activities) that there is a sufficient degree of land divisibility[1] to enable the type of management depicted by the model. It will be seen that this assumption becomes less restrictive when new technology is developed. The area planted with pastures and the level of cattle activities tend to decline as new technology in corn production becomes available.

Analysis of Results

The programmed plans for a hypothetical farm with and without cattle activities is compared with the actual plans obtained from survey data.

Trying to represent and get a better understanding of the actual production process in the area, subjective restraints were included in the model. A subjective

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[1]The type of rotations defined in the model require a certain number of fields with good fences and water facilities that are not always found on farms of the size considered in the model. This type of management is more likely to be found on larger farms where the proportion of land under pasture and cattle activities is larger than on our hypothetical farm.

restriction is introduced for a rotation including soybean as a double cropping activity.

The soybean has been recently declared a crop of national interest with a high support price to promote its production, making this activity highly profitable. Soybean enters into the optimum plan at the maximum level allowed by the restriction. The actual area planted with soybean in Caseros county is rather low since it is a new crop and farmers still are not familiar with it.

A subjective maximum of 25 sows is also introduced into the model. Fluctuations in hog prices and lack of a sanitary program limits the extent to which farmers can expand hog production.

Results, in terms of optimum plans and actual farm plans for both farm types, are presented in Table 4.1.

The most profitable rotation is wheat/soybean-corn which enters at its 40 hectares maximum,[1] followed by rotations including pastures and continuous corn for farms with and without cow activities, respectively.

Two rotations in both programs provide the optimum cropping plan. Differences in total hectares of each crop compared with farmers' existing production patterns are

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[1]Wheat/soybean-corn, 40 has = wheat 20 hectares, soybean 20 hectares, corn 20 has.

Table 4.1. Actual plans and optimum plans for farms with and without beef activities

Activity	Model 1		Model 2		
	Optimum Plan	Actual Plan[a]	Optimum Plan	Actual Plan[b]	Actual Plan[c]
Corn has.	43.3	43.2	66.7	49.4	53.
Wheat has.	26.6	20.9	20.	23.8	33.
Pastures has.	16.7	21.8	0.	7.2	6.5
Soybean has.[d]	20.	10.	20.	5.	
Sunflower has.[d]	0.	4.1	0.	10.5	15.
Cows heads	20.	20.			
Calves heads[e]	8.	9.8			
Heifers heads[e]	0.	4.			
Steer[e]	7.	7.7			
Slaughter steer[e]	1.	5.			
Hogs sows[f]	25.	8.4	25.	5.4	9.
Hogs pasture has.	8.2		8.2		
Area planted	95.	86.	95.	80.4	92.5
Total area	95.	92.4	95.	85.	96.

[a]Average number of hectares planted and head of cattle for 18 farms in the size farm strata 60 to 120 hectares.

[b]Average number of hectares planted and number of sows for 10 farms in the size farm strata 60 to 120 hectares.

[c]Average number of hectares planted and number of sows for 4 farms of approximately the same size as the hypothetical farm.

[d]Double cropping activities. Soybean and sunflower are planted after harvesting wheat.

[e]While the survey shows the actual stock by type, figures in the model represent number of head sold during the period.

[f]2 litters per year; 1 litter = 5 pigs.

slight.

Farmers with cow activities get the cheapest source of forage from $W\text{-}PP_5\text{-}C_5\text{-}W\text{-}C\text{-}C$.[1] Corn returns higher revenue than other crops; thus rotations that include the highest proportion of corn and meet forage requirements are most profitable. Farms without cattle plant pastures mainly for hog and hay production.

Given the low proportion of pasture in both groups of farms, most of the corn is planted on land that has not been under pasture for periods varying from six to nine years. Corn yields in model 1 are assumed to decline as corn moves farther from pasture in the rotation.

In the model without cow activities continuous corn should be understood as corn planted on fields that have not been under pasture for periods longer than nine years.

Survey data shows that pastures are incorporated into the rotation, as an average, every eight to nine years. When farmers were asked what is the best rotation to increase corn yields the most common answer was, "three to four years of pasture followed by three to four years of corn". Even though they know that higher corn yields can be expected through shorter rotations with pastures, the income

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[1] Two wheat crops, five years of pasture and seven corn crops.

loss incurred by introducing pastures more frequently is greater than the loss due to the decline in corn yields. This will be seen more clearly in the next section.

Optimum plans and income penalties

Optimum plans and income penalties[1] incurred by forcing one unit of activity into the optimum plan are presented in Table 4.2.

Rotations which include larger proportions of corn show lower income penalty for farms in model 1.

The optimal solution includes the rotation Wh-PP_5-C_5-Wh-C_2 which incorporates permanent pastures every nine years. After the ninth year of continuous cropping it is assumed that corn yields will be such that if one unit of corn activity were forced into the solution the value of the program would decrease by 45.50 pesos.

Table 4.2 shows that the shorter the rotation pattern or the larger the area under pastures, the higher the income penalties. Given the actual factor-product relationships and technology available to the farmers, there are no economic incentives to move to shorter rotations. A crop rotation pattern directed to improve soil fertility and to

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[1]Shadow prices or reduced cost for production activities indicate how the value of the program would change if a unit of activity were forced into the plan (6).

Table 4.2. Optimum plans and income penalties for farms with and without cattle activities[a]

Rotation	Model 1		Model 2	
	Activity hectares	Reduced cost (pesos)	Activity hectares	Reduced cost (pesos)
C		45.50-	46.75	
Wh-PP_5C_5-Wh-C-C	46.75			-[b]
Wh-G_4-C_3	.	58.39-		
Wh-G_4-C_3-W/Su_2	.	50.90-		
Wh/PP-PP_4-C_4-Wh-C	.	29.14-		
Wh-C	.	58.12-		13.33-
Wh-PP_5-C_5-Wh/Su	.	23.57-		
Wh/Su-C	.	62.25-		16.87-
Wh	.	111.00-		66.94-
Cow heads	20.1			-[b]
Heifer calves	8.0			
Steer calves	.	87.50-		
Yearling steer	.	95.37-		
Steer	7.00	.		
Slaughter steer	1.00	.		
Beef selling activity (kg)	5099.85	.		
Sows	25.00	.	25.	.
Wh/So-C	40.00	.	40.	.
Corn selling activity cwt	1097.26	.	1606.84	.

[a]Wh: wheat, G: grassland, C: corn, Su: sunflower, So: soybean, PP: permanent pasture, Wh/PP: pasture planted with wheat, slash: double cropping activity, subindex: number of years crop enters into the rotation. The same notation will be used throughout this study.

[b]Rotations including pastures and cattle activities were not included in the model.

increase corn yields seems to be incompatible with the objective function of the farmer.

It is expected that the introduction of green manure, nitrogen fertilizer and changes in cattle feeding technology will enable farmers to improve soil fertility, leading to higher corn yields.

In model 2 corn and Wh/So-C enters into the optimal solution. The corn activity through its yield coefficient reflects corn planted on low soil fertility fields. Farmers through rotations with wheat and intensive seedbed preparation[1] maintain a certain soil fertility level making it profitable to go back to corn again.[2]

Model 2 in Table 4.2 shows that if one unit of Wh-C activity were forced into the plan the value of the program would be reduced by 13.33 pesos. Even though through rotation with wheat, which allows a seven month fallow period, higher corn yields can be obtained; the gain in yield is not enough to compensate for the loss in income incurred by

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[1]By intensive seedbed preparation during the winter, farmers control weeds, improve soil water holding capacity and aerate the soil, speeding up the rate of release of nitrogen by the soil.

[2]Survey information shows that fields that have not been under pasture or alfalfa for periods varying from five to more than 10 years include one or two years of wheat and go back to corn again. Through this type of soil management farmers also control corn soil insects, diseases and weeds.

introducing wheat into the rotation.

Comparing results from the model and survey information about rotations, it appears that farmers introduce wheat into the rotation to avoid soil depletion and substantial reductions in corn yields. By following this type of management farmers incur an income loss.[1] It is expected that this group of farmers will be the ones that will benefit the most by the introduction of available technology.

Value of the program and resources used

Net returns after variable cost for model 1 are higher than for model 2. In model 1 average corn yields are higher and cattle activities contribute to the higher value of the program.

Labor supply corresponds to one man per year. The total number of hours available for field work was not limiting in any of the periods considered in the model.

Dual activity values of resources

The dual activity value of a particular resource may be interpreted as the marginal value productivity of that resource.

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[1]The amount of income forgone by introducing Wh-C rotation will depend on the level or number of hectares planted. The model does not provide the range and the level at which the 13.33 pesos income penalty changes its value. This would require a range analysis.

Table 4.3. Optimal net returns above variable cost and resources used for farms with and without cattle activities

Item	Model 1	Model 2
Net returns above variable cost	66703.85	61541.64
Land	95.00	95.00
Operating capital	27660.00	10682.55
Total man labor hours		
May 1 - July 15	562.50	442.26
July - September 15	412.00	320.28
September - November 15	454.15	333.76
November - January 30	420.92	314.40
February - April 30	365.20	262.70

Land exhibits the highest dual activity value in model 1. A decrease in one unit of land will reduce the returns of model 1 by 258.936 pesos. The same interpretation applies to the dual activity values of land in model 2.

The returns to capital in model 1 are below the annual market rate of interest of 16 percent. The returns to capital in the model will depend on the level of use of other resources included in the program. During the May-September

Table 4.4. Dual activity values of resources for farms with and without beef activities[a]

Resource	Model 1		Model 2	
	Dual Activity	Slack Activity	Dual Activity	Slack Activity
Land	258.93-		217.68-	
Capital	.15-		.08-	
T.D.N.[b]				
March-May		13510.21		-[c]
May-September	.27-	.		-[c]
September-December		10657.67		-[c]
December-March		1902.85		-[c]
Labor (hours)				
May-July 15		.		120.24
July-September 15		.		91.71
September-November 15		44.84		165.23
November-January 30		195.04		301.60
February-April 30		234.79		337.30

[a]Only values relevant for the analysis are presented.

[b]Total digestible nutrients.

[c]Rotations with pastures were not included in model 2.

winter months forage becomes limiting. Supplemental feeding or the introduction of annual highly forage productive winter pastures in the program could result in a release of this constraint and in higher returns to working capital.[1]

In model 2 the returns to capital denote the point at which the additional return obtained from an extra unit of operating capital just equaled the assumed rate of interest per six months.

Model 1 reflects a management system that is common in farms with cattle activities. Wheat and corn fields are grazed after harvesting for periods of time that vary with the crop that follows in the rotation. The slack activities show the roughage surplus for periods other than winter.

In model 1 activities were introduced to reallocate slack labor to certain cattle operations that do not need to be carried out within a specific period of time. Slack labor is completely used up in those operations during the May-September period, as shown in Table 4.4.

Discussing the Results

While differences exist between farms, in terms of area planted under different crops compared to our hypothetical farms; farmers seem to be aware of price

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[1]Supplemental corn feeding activities and their effect on optimum farm plans will be explored in Chapter V.

relationships when they choose their output mixes.

In Chapter II survey data were presented showing that fields that have not been under pasture for periods longer than five years introduce wheat in the rotation with corn.

Given the actual price relationships wheat seems to enter into the rotation as a means to restore soil productivity and control corn soil insects, diseases and weeds. By doing so farmers incur an income loss that is lower than if they continue planting corn on the same field.

In Chapter II corn production practices available at the experimental level were discussed and compared to practices farmers are actually using. It was shown that farmers are doing what under experimental conditions ended up being the best. Efforts to disseminate this information and improve timing of operations under farm conditions will result in little gains in corn yield unless soil fertility levels are restored.

Comparing results of optimum plans for both farm types with actual farm plans, it seems that farms with cattle operations will be able to have better soil management through rotations with pastures than farms represented by model 2.

Model 1 shows that crop rotation patterns, directed to improve soil fertility levels and corn yields through shorter rotations with pastures, will result in income losses. Farmers seem not to have any economic incentive to follow more rational soil management plans. Management decisions directed to avoid soil depletion and obtain higher corn yields will result in a lower value of the program. There seems to be a conflict between the objective function of the farmer and maximization of corn yields.[1]

The introduction of chemical fertilizer could allow farmers to restore soil fertility levels and improve soil conditions through changes in production practices and rotation patterns. This possibility will be explored in the following chapter.

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[1]Maximization of corn yields should be understood in terms of yields obtained under experimental conditions.

CHAPTER V. IMPROVED CORN PRODUCTION TECHNOLOGY

This chapter shows how optimal farm plans will be affected by the introduction of improved technology in corn production.

The first part will show the effect of technology available today in Argentina on optimum farm plans.

The second part will be devoted to two effects on optimum farm plans if highly fertilizer-responsive hybrids and new production practices were developed.

Analysis of Results Under Present Technology

Two means of increasing soil fertility and corn yields in Caseros county will be analyzed:

1. Green manure (using red clover or green vetch) in the rotations;
2. Anhydrous ammonia as a source of nitrogen.

Activities including red clover and green vetch in the rotation are introduced in the model. Fertilized corn activities represent fertilizer applied on fields subject to a very intensive cropping pattern. In model 1 fertilized corn activities compete for resources with corn activities including pastures and green manure in the rotation. In model 2 representing farms with very low area under pastures,[1] fertilized corn activities compete for resources with green manure and crop activities without fertilizer.

The coefficients reflecting corn yield response to fertilizer were based on the response function for the INTA-CIMMYT-FF experiments.[2] The yield coefficients were reduced to reflect the expected response under farm conditions.

Under experimental conditions, Atrazin was used for weed control. Also, experimental conditions harvest losses are considered to be a minimum. But it is furthermore expected that under farm conditions limiting factors will appear sooner at high rates of fertilization than under experimental conditions.[3]

The capital and objective function coefficients of the activities representing available technology in corn production reflect the increase in requirements of operating capital and the cost of additional operations required by

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[1]In Table 4.1 it was shown that the actual area under pasture for this particular group of farms varies between 7 to 8 percent of the total area.

[2]Corn yield response under different levels of fertilizer were presented in Table 3.4.

[3]A reduction in yield response of 10 percent for levels of fertilization up to 30 units of nitrogen per hectare was assumed. Fertilizer response is gradually reduced to 15 percent for levels between 30 to 60 units of nitrogen and reductions of 15 percent are maintained for levels above 60 units up to the maximum corn response with 90 units of nitrogen per hectare.

the new factors and practices.

In model 1 the restriction on capital is maintained at the same level. This will enable operating capital to be reallocated between cattle activities and activities representing available technology. Model 2 maintains the operating capital borrowing activity.

In both models it is assumed that the new factors are cash payments. Fertilizer in the area can be paid for after harvest but the credit cost is above the bank rate of interest.

Labor coefficients reflect the extra labor required for planting green manure, application of fertilizer and harvesting time due to higher corn yields.

Optimum plans

In this section results in terms of optimum rotations are presented for the two model farms.

The available technology at the experimental level includes rotation Wh/R.Cl-C,[1] with red clover as green manure. After harvesting wheat in November, red clover remains on the field until June when it is plowed under. The returns in the objective function reflect a lower wheat yield, due to the use of lower wheat seeding rates per hectare, when

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[1]Wheat and red clover are planted in the same operation.

wheat is planted with red clover.

Two more rotations proposed for the area are included in the models. Activities Wh-CV-C[1] and C-GV-C include green manure planted in March. Green manure activities are grazed for short periods of time before being plowed under. In model 2 land devoted to green manure remains unproductive for periods varying from five to seven months.

Corn yield coefficients for activities including green manure reflect a response directly related to the period of time the field is under green manure and the mass of green material produced.

Optimum plans and income penalties for both models are presented in Table 5.1. Results in this table show that at a fertilizer-corn price relationship of 9, neither fertilizer nor green manure activities enter into the optimal solution of model 1.

The new technology proposed in terms of green manure competes for land with pastures and corn. Even though green manure activities provide forage during the winter period the traditional management system remains more profitable. Given the relatively low corn-fertilizer response and the high price of fertilizer assumed in the model under present technology, it will not be profitable for farmers in this

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[1]Wheat-green vetch-corn.

Table 5.1. Optimum plans and income penalties under available technology[a]

Rotation	Model 1		Model 2	
	Activity hectares	Reduced cost (pesos)	Activity hectares	Reduced cost (pesos)
C	.	45.50-	.	5.15-
Wh-PP_5-C_5-Wh-C_2	46.75	.		
Wh-G_4-C_3		58.39-		
Wh-G_4-C_3-W/Su_2		50.90-		
Wh/PP-PP_4-C_4-Wh-C		29.14-		
Wh-C		58.12-		18.48-
Wh-PP_5-C_5-Wh/Su		23.57-		
Wh/Su-C		62.25-		
Wh		111.00-		
Cow heads	20.1	.		
Heifer calves	8.0			
Steer calves		87.50-		
Yearling steer		95.37-		
Steer	7.0	.		
Slaughter steer	1.0	.		
Beef selling activity (kg)	5099.85	.		
Sows	25.00	.		

[a]Same notation as in Table 4.2.

Table 5.1 (Continued)

Rotation	Model 1 Activity hectares	Model 1 Reduced cost (pesos)	Model 2 Activity hectares	Model 2 Reduced cost (pesos
Wh/So-C	40.00	.		
Corn selling activity cwt	1097.26	.	1823.76	.
Wh/R.Cl-C		25.00-		8.21-
Wh-GV-C		37.02-		23.28-
C-GV-C		61.02-		17.93-
C_N 30 units[b]		43.73-	46.75	

[b]Fertilized corn and number of nitrogen units applied.

group to use chemical fertilizer. If one unit of fertilized corn were forced into the solution, the value of the program would be reduced by 43.73 pesos.

Model 2 shows that it is profita le for farmers in this group to fertilize corn with 30 units of nitrogen per hectare. In the next section it will be seen that even though it is profitable to apply fertilizer at the price relation of 9, returns to capital invested on fertilizer are very low.

<u>Value of the program</u>

Using modified simplex solutions, optimum levels of fertilization were determined for different fertilizer-corn price relationships.

The value of the program, levels of fertilization and returns to operating capital invested on fertilizer are presented in Table 5.2.

Model 2 in Table 5.2 shows that at the price relationship of 9[1] it is profitable for farmers to use 30 units of nitrogen per hectare. When the survey was conducted the price relationship was approximately 8. Thirty percent of the farmers included in the sample have used fertilizer on corn at least once although only 10 percent use it every year.[2]

Model 2 shows that at a price relationship of 9 returns to operating capital invested in fertilizer are very low. The low returns to capital, the lack of enough information and the risk involved in the use of this new technology could explain the low rate of adoption of chemical fertilizer in the area.

Net returns above variable cost and returns to operating capital increase at each parametric step. They reach

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[1]Price 1 kg of nitrogen/1 kg of corn.

[2]Survey information does not reveal if the total area planted with corn on the farm was fertilized.

Table 5.2. Optimal net returns above variable cost for different nitrogen-corn price relationships

Price relat.	9		7		5		3	
Item	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Net returns (pesos	66703.8	61782.4	66703.8	62286.7	66703.8	63005.1	66712.9	64056.9
Operating capital (pesos)	27660.0	12879.8	27660.	12970.9	27660.	12728.3	27660.	12422.1
Optimum level of fertilizer (nitrogen/ha)	0	30	0	40	0	50	70[a]	70
Total corn sold (hundred kg)	1097.2	1823.7	1097.2	1872.8	1097.2	1911.6	1127.3	1971.49
$\frac{B}{C} \times 100$[b]		10.95		32.5		71.53		144.5

[a]Total area of fertilized corn in the optimum plan was 1.6 hectares.

[b]Benefits and costs estimated by the increase in the value of the program and operating capital. To transform to returns to capital per year it is necessary to multiply by 1.7; assuming corn production is marketed after harvest.

the highest value at the lower price relationship considered in the model.

Higher rates of return have been estimated for fertilizer on corn in Argentina (9). The differences can be accounted for by lower response under actual farm conditions, cost of fertilizer application, harvesting cost and the interest on operating capital.

At the most favorable price relationship considered in the model it will be profitable to apply 70 units of chemical fertilizer under conditions of perfect certainty. Higher rates of fertilization will require lower price relationships.

The maximum fertilizer response under present technology (assuming a zero cost of fertilization) seems to be around 99 units of nitrogen per hectare.[1]

Reductions in the actual price of fertilizer will allow heavier rates of fertilization. de Janvry (9) shows that a reduction in the price of fertilizer will increase the probability of farmers at least covering fertilizer cost under unfavorable weather conditions.

Under the most favorable price relationship considered,

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[1]Plant populations in INTA-CIMMYT-FF fertilizer on the average varied from 44 to 46 thousand plants per hectare. At higher plant populations fertilizer-response could be higher.

farmers represented by model 2 will increase total corn production by 22 percent. In model 2 corn following soybean in the rotation is not fertilized. It is assumed that under available technology the response of corn to fertilizer will be very low.

In model 1, even at the most favorable price relationship considered in the model, the area of fertilized corn is very low. It is expected that under present technology this group of farmers will demand lower amounts of chemical fertilizer.

Implications of the Results

In model 1 it is assumed that land is homogeneous and all suitable for cropping activities and that the farm is subdivided in sufficient numbers of fields to allow the type of management depicted by the model.

This is not always the case. Lower quality land or a few fields with good fences and water facilities are devoted to beef activities and the rest of the land is subject to an intensive cropping pattern. Model 1 also assumed a management of pastures and a certain positive effect on soil fertility levels that not always is found on farms of this size.[1]

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[1]Due to land indivisibilities and particular weather conditions pastures many times are overgrazed resulting in a lower contribution to increased soil fertility levels.

Management through rotations with pastures as shown in model 1 is more likely to be found on larger farms than the hypothetical farm size used in this study.

Finally in interpreting the results in model 1 it has to be taken into consideration that the beef-corn price relationship was one of the highest that has existed in the last ten years.[1] The price relationship increased from approximately 7 during the period 1967-1969 to 10 in 1971.[2]

Optimum programming solutions will be presented later in this chapter for varying fertilizer, corn and beef price relationships. How the development of highly fertilizer-responsive hybrids and changes in feeding cattle technology will affect farm plans in model 1 will also be discussed.

<u>Dual activity values of resources</u>

Table 5.3 presents the dual activity values and slack activity values of resources used in model 2 for different fertilizer-corn price relationships.[3]

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[1]This mainly was due to a severe reduction in cattle stock in Argentina.

[2]Price relationships estimated after deducting marketing costs.

[3]Dual activity and slack activity values for model 1 remain the same for price relationships of 9, 7 and 5 as those presented in Table 4.4. At a fertilizer-price relationship of 3, 1.6 hectares of fertilized corn enters in the optimum plan slightly altering the values.

Table 5.3. Dual activity values of resources for different levels of fertilization in model 2[a]

Resource	Fertilizer Price Relationship							
	9		7		5		3	
	Dual Activity	Slack Activity	Dual Activity	Slack Activity	Dual Activity	Slack Activity	Dual Activity	Slack Activity
Land	222.83-	.	233.61-	.	248.98-	.	271.48-	.
Capital	.08-	.	.08-	.	.08-	.	.08-	.
Labor (hours)								
May-July 15	.	120.24	.	120.24	.	120.24	.	120.24
July-September 15	.	91.71	.	91.71	.	91.71	.	91.71
September-November 15	.	132.51	.	120.17	.	127.83	.	123.16
November-January 30	.	301.60	.	201.60	.	301.60	.	301.60
February-April 30	.	332.62	.	327.95	.	327.95	.	323.27

[a]Levels of fertilization correspond to 30, 40, 50 and 70 units of nitrogen per hectare.

The dual activity[1] value of land increases as the fertilizer-corn price relationship declines. Removing one unit of land from production will result in a decrease in net returns after variable cost equal to the dual activity value for land.

The dual activity value of operating capital equal to 0.08 pesos denotes the point at which the borrowing of additional operating capital stopped. At this point the additional return obtained from an extra unit of operating capital just equaled the assumed rate of interest per six months.

The dual activity values for operator's labor is zero for the five different periods considered in the model. The most critical period is July-September as shown by the value of the slack variable. The value of labor slack variables during the September-November period decline, reflecting the additional labor required to apply higher rates of fertilizer. During the February-April period declines in labor slack variables show the additional labor required at harvesting time. Labor requirements in other periods remain the same reflecting no changes in production practices other than application of fertilizer.

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[1]Dual activity value is equal to the shadow price of a given resource.

Price map

The price map presented in Figure 6 shows the price relationships at which optimum plans in terms of fertilized corn, green manure, cattle and pasture activities change, subject to the restrictions included in model 1.

The boundaries presented in Figure 6 show changes in groups of activities. Within a given area of the price range changes in the proportions between activities and rates of chemical fertilization as price relationships vary take place. These changes are not reflected in the price map. The purpose is to show the feasibility of available technology being adopted at different price relationships.

Starting along the horizontal axis and at a fertilizer-corn price relationship higher than 9, green manure activities enter into the optimum plan. As the price of beef with respect to corn increases more cattle and area planted with pastures enters into the optimum plans reducing the level of Wh/R.Cl-C activity.[1] At a beef-corn price relationship of 8.02 it is profitable to extend the fattening process. More land is devoted to pastures and steers are sold at heavier weights. At the highest corn-beef price relationship

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[1]Green manure rotation wheat/red clover-corn.

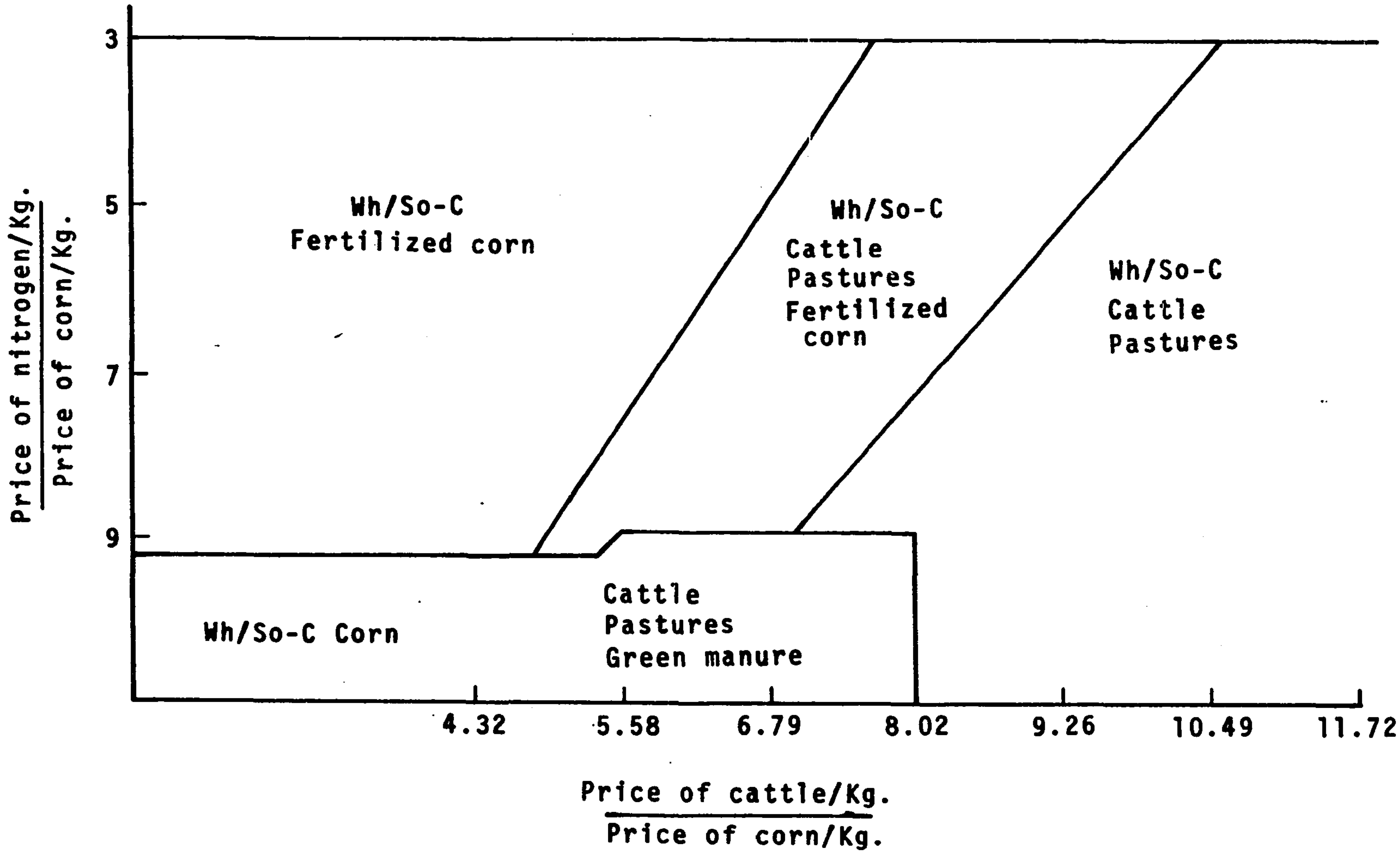

Figure 6. Price map for optimum farm plans varying prices of cattle and nitrogen fertilizer

and for the level of working capital assumed in the model, the value of the marginal productivity of capital is 0.17.[1] Labor is not restrictive in any of the periods considered in the model.

The dual activity value of TDN during the winter period is 0.31, well above the selling price of corn of 0.162 pesos per kilogram.[2] This suggests that the use of corn as supplemental feeding during the winter period could be profitable.

Moving up along the price fertilizer-corn axis, as the price ratio declines, higher rates of chemical fertilizer are used. No cattle and pasture activities enter into the optimum plans. This result corresponds to model 2, in which no cattle activities were included in the program.

Assuming a fertilizer-corn price ratio of 3, and moving along the upper limit of the figure, the beef-corn price relationship increases. At a price ratio of 6.79[3] no cattle activities and pastures yet enter the optimum plan. Further increases in the price relationship bring about changes

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[1]The bank interest rate, during the period of this study, was 16 percent.

[2]Price received by the farmer after marketing costs.

[3]This price relationship prevailed before the shortage of beef stock.

in optimum plans. Cattle activities, pastures and fertilized corn enter into the optimum solutions.

At the highest beef-corn price ratio of 11.72 considered in the model and with the available technology no fertilizer will be used. Profitability of cattle activities increases as the price of beef increases. The level of cattle and pasture-crop rotation activities increases competing for resources with fertilized corn activities. The area under pasture reaches a level in which the traditional management is more profitable. The fattening process is extended and the optimum farm plan ends up being the same as described before at a beef-corn price relationship above 8.02 and a fertilizer-corn ratio of 9.

Labor will not be limiting in any of the periods considered in the model despite the increase in the level of cattle activities. Expansion of cattle activities is limited by available TDN during the winter period and working capital.

The marginal productivity value for TDN during the winter period (May-September) is equal to 0.31 pesos. During this period it will be profitable for the farmer to use supplemental feeding[1] until the cost of the last TDN used

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[1]This possibility will be explored in the next section.

is equal to its marginal value productivity.

Operating capital marginal productivity value is equal to 0.17 pesos, above the annual bank interest rate of 0.16 pesos, prevailing during the period of this study. It would be profitable for the farmer to borrow money at the lending rate in order to expand his activities until other resources included in the program become limiting, or the returns to the last unit of operating capital is equal to the lending rate.

It was shown in Table 5.2 that the lower the price fertilizer-corn ratio the higher the rate of return to operating capital. Reductions in the price of fertilizer will make it profitable for farms without cattle activities and low soil fertility levels as assumed in model 2 to adopt chemical fertilizer. A high rate of return on fertilizer could induce farmers with a high subjective risk aversion to a faster rate of adoption. Also de Janvry (9) has shown that the lower the price of fertilizer the higher the probability of at least covering its cost.

At the fertilizer-corn price relationship of 8, when this study was conducted, the price map shows that rotations including green manure are not included in the optimal plans. As the fertilizer-corn price ratio declines higher rates of fertilization enter into the optimum plans making it more profitable to use chemical fertilizer than green manure.

High levels of nitrogen fertilization contribute more nitrogen to the soil than green manure, resulting in higher corn yields.

Also the price map shows, assuming no restrictions in capital, that at fertilizer-corn price relationships above 9 it will be more profitable to restore soil fertility levels through rotations including green manure and pastures than with chemical fertilizer.

Finally, even assuming a substantial decline in the price of fertilizer, farms following the type of management described in model 1 will demand lower amounts of fertilizer.

In the next section the effect on farms with cattle activities of a low fertilizer price policy together with the development of highly fertilizer-responsive hybrids and new production practices will be analyzed.

Analysis of Results Under New Technology

In this section the impact of highly fertilizer-responsive hybrids and new production practices on farms with cattle activities will be analyzed.

Two variants of model 1 are presented. Model 1A includes transfer rows and corn feeding activities. Corn can be used to feed cattle or can be sold at 0.16 pesos per kilogram in the market. In model 1B it is assumed that no supplemental feeding technology is available to the farmers.

It is assumed that due to the use of preemergence herbicides, changes in production practices and use of highly fertilizer-responsive hybrids response to nitrogen fertilizer will be higher than with the present technology. Changes in production practices would improve soil structure and subsoil moisture conservation, this and better weed control due to the use of preemergence herbicides would reduce corn sensitivity to summer droughts and increase corn yields.

Four levels of fertilization[1] are considered in the model. It is assumed that for levels of fertilization of 30, 60 and 90 units of nitrogen per hectare the yield response, under average weather conditions, will be 15, 22 and 28 percent higher than with the present technology. The maximum corn yield of this theoretical response will be above the 120 units of nitrogen considered in the model.

It is assumed that fertilized corn fields are not grazed after harvesting and that corn stalks are incorporated into the soil in order to improve soil physical conditions.

Labor and working capital coefficients reflect changes in production practices and cost of preemergence herbicide. The fertilizer-corn price relationship is assumed to be 3.

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[1]The levels of fertilization considered in the model are 30, 60, 90 and 120 units of nitrogen per hectare.

The same beef price of 1.70 pesos per kilogram will be used in this analysis.

<u>Optimum plans and income penalties</u>

Results for the two variants of model 1 are presented in Table 5.3.

Assuming technology and factor-product price relationships remain the same for other activities, the development of highly fertilizer-responsive hybrids and improved production practices will make fertilizer corn activity highly profitable. This will result in a shift of resources from other activities to corn leading to an area specialization in crop production. This effect will be less pronounced by the introduction of corn supplemental feeding technology for cattle.

In model 1A by the introduction of corn supplemental feeding activities, cattle remain in the optimal solution. The reduction in the number of cows[1] together with an increase in pasture receptivity releases land that is devoted to corn. Fertilized corn enters into the optimum plan at the maximum rate of fertilization of 120 nitrogen units considered in the program. If one unit of nonfertilized

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[1]The total number of cattle in Table 5.1 with available technology and a fertilizer-corn price relationship of 9 was 36.

Table 5.4. Optimum plans and income penalties under new technology

Rotation	Model 1A Activity hectares	Model 1A Reduced cost (pesos)	Model 1B Activity hectares	Model 1B Reduced cost (pesos)
Wh-PP_5-C_5-Wh-C-C		7.28-		9.95-
Wh-G_4-C_3		49.21-		101.50-
Wh-G_4-C_3-W/Su_2		68.81-		84.29-
Wh/PP-PP_4-C_4-Wh-C		56.76-		22.26-
Wh-C		145.50-		93.19-
Wh-PP_5-C_5-Wh/Su	7.33	.		52.56-
C-Wh/Su		172.55-		96.06-
Wh		174.04-		226.66-
Cows (heads)	6.31	.		.
Heifer calves	2.52	.		.
Steer calves		18.63-		63.06-
Yearling steer		35.47-		95.72-
Steer	2.52			.
Slaughter steer		75.26-		78.86-
Beef selling activity kg	1566.15			
Sows	25.		25.	
Corn selling activity cwt	2283.78		2578.77	
Corn feeding activities				-[a]

[a]Corn feeding activities were not included in the model.

Table 5.4 (Continued)

Rotation	Model 1A Activity hectares	Model 1A Reduced cost (pesos)	Model 1B Activity hectares	Model 1B Reduced cost (pesos)
May-September cwt	45.70			
September-December cwt	.57			
Wh/So-C	40.00		40.00	
C 120 units	39.41		46.75	.
C 90 units		13.08-		13.08
C 60 units		44.96-		44.96
C 30 units		93.96-		93.96-
C 0 units		157.17-		.
Wh-RC1-C		137.83-		119.93-
Wh-GV-C		151.86-		141.28-
C-GV-C		168.61-		167.86-

corn were forced into the optimum plan the value of the program would be reduced by 157.17 pesos.

Wheat is mainly produced in rotation with soybean as a double cropping activity. It is assumed in the model that corn following soybean in the rotation will have a low response to fertilizer.[1] This assumption will become weaker as higher fertilizer-responsive hybrids are developed. Demands for nitrogen as more fertilizer-responsive hybrids are developed probably will exceed the contribution of nitrogen to the soil by soybean, making it profitable to fertilize corn.

Model 1A also shows that the requirements of roughage for cattle activities are met through shorter rotations with pastures and supplemental feeding with corn during the winter period (May-September).

The model indicates that cattle activities will decline by introducing the new technology, increasing the area of fertilized corn.

In model 1B, no corn feeding activities are introduced into the model. Table 5.4 shows that no cattle activities enter into the optimum solution. The income penalties incurred by forcing one unit of cow activity into the program can be derived from the income penalties attached to activities including pasture in the rotation.[2]

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[1]Shrader (46) reports that soybeans contribute about 1 pound of nitrogen to the soil for each bushel of beans produced.

[2]One unit of cow activity in the program will demand TDN supplied by rotations with pastures. The proportion of pasture activity demanded times its income penalty will be the income penalty corresponding to one unit of cow activity forced into the program.

The model indicates that the unavailability of a supplemental feeding technology will end up in a complete crop specialization.

Value of the program and resources used

Model 1A realizes a higher net return above variable cost than model 1B. Also the amount of operating capital[1] needed to carry out the plan is higher than in model 1B.

Corn feeding activities reflect through their coefficients the amount of labor required to feed the cattle during different periods of the year. Most of the difference in labor hours required by model 1A during the period May-September are accounted for by the extra labor needed for feeding cattle. Differences in other periods can be accounted for by variations in farm plans and labor requirements of cattle activities.

Dual activity values of resources

Table 5.6 presents the dual activity values and slack activity of resources for the two variants of model 1.

Model 1A shows that the TDN shadow price is above the cost of one unit of TDN provided by corn during the period

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[1]Operating capital has been defined as the amount of operating capital needed during a peak period. It is assumed in the model that cattle can be sold if more operating capital is needed.

Table 5.5. Optimal net returns above variable cost

Item	Model 1A	Model 1B
Net returns (pesos)	69473.72	69387.86
Operating capital	19463.99	14655.83
Total man labor hours		
May 1 - July 15	459.94	315.10
July - September 15	412.00	351.14
September - November 15	378.24	362.28
November - January 30	349.88	314.40
February - April 30	379.67	366.48

Table 5.6. Dual activity values and slack activities of resources

Resource	Model 1A		Model 1B	
	Slack Activity	Dual Activity	Slack Activity	Dual Activity
Land (pesos)	.	376.45-	.	380.51-
Operating capital (pesos)	8196.60	.	13004.16	.
Total man labor hours				
May 1-July 15	102.55		247.40	.
July-September 15	.	1.41-	60.86	.
Sept.-November 15	120.75	.	136.72	.
Nov.-January 30	266.11	.	301.60	.
Feb.-April 30	220.32	.	233.51	.
Total digestible nutrients				
March 15-May 15	72.65	.		.15-
May-September 15	.	.32-		.33-
Sept.-December 15	.	.20-		.
December-March 15	.	.06-		.

May-September.[1] It is still profitable for the farmer to feed cattle with corn during that period. The model also shows that supplemental feeding could be profitable for the farmer in other periods of the production process.

The shadow price of one hour of labor during the July-September period is 1.41 pesos--below the minimum official wage rate of 1.55 pesos per hour. The hiring of one hour of labor will result in a reduction of 0.14 pesos in the value of the program.

The number of cows in the optimum solution declines from 20 (Table 5.1, Model 1) to 6. In model 1B it is assumed that supplemental feeding technology is not available, and no cattle activities enter into the optimum plan.

Summary

This chapter discussed how optimal farm plans would be affected by the introduction of improved technology available in Argentina. Farms with cattle activities through rotations with pastures maintain soil fertility levels. Even at the most favorable fertilizer-corn price ratio of 3 considered in the model the demand for fertilizer by this group of farms would be very low. Farms without cattle activities,

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[1]One unit of corn is equal to 0.80 TDN. One unit of TDN provided by corn will cost 0.20 pesos.

low areas under pastures and fields subject to a very intensive cropping pattern show response to fertilizer. The corn yield response is such that under the most favorable fertilizer-corn ratio considered in the model corn yields are approximately the same as those obtained in soils that have been under pasture.

Due to reductions in the fertilizer-corn price ratio and the development of highly fertilizer-responsive hybrids, use of preemergence herbicides and changes in production practices, response to nitrogen and rates of fertilization will be higher than under present technology.

Two alternatives for farms with cattle activities were presented. The development and use of corn supplemental feeding technology would reduce the area under pasture and increase pasture receptivity. Cattle roughage requirements will be met through shorter rotations allowing farmers a better soil management. Total area under fertilized corn and rates of fertilization will be higher than under present technology.

In model 1B it was assumed that supplemental feeding technology was not available. Cattle activities do not enter into the optimum solution resulting in a complete crop specialization.

CHAPTER VI. CONCLUSIONS AND IMPLICATIONS

There were three major objectives in this study presented in Chapter I.

The first objective was to determine the feasibility of different types of farmers adopting nitrogen fertilizer.

Farms with cattle activities show larger areas under permanent pastures. It was shown from survey data that there exists a positive association between area under pasture and corn yields.

Given the assumption in the model that farms with cattle activities will be able to practice better soil management through rotations with pastures and maintain soil fertility levels, even at the lowest fertilizer-corn price ratio of 3, this group of farmers will demand lower amounts of nitrogen fertilizer under available technology.

Farms characterized by low area under pasture and no cattle activities show that at the prevailing fertilizer-corn price ratio of 8 and assuming perfect certainty it will be profitable to use 30 units of nitrogen per hectare. Given the risk involved in the adoption of the new technology the returns to operating capital invested in nitrogen fertilizer were very low. This in part could explain the low rate of adoption of fertilizer in the area. Thirty percent of the farmers reported to have used nitrogen fertilizer on corn at least once and only 10 percent were using it every year.

A reduction in the price of fertilizer will be most beneficial to small farmers who follow an intensive cropping rotation pattern and who have a very low area under pastures. The reduction in fertilizer price will allow this group of farmers to restore soil fertility levels and to get higher corn yields comparable to those obtained by farms with high soil fertility levels.

It was also shown that at the fertilizer-corn price ratio of 8 it was not profitable to use green manure in rotation with corn. The contribution of nitrogen to the soil by green manure presents a biological limit related to the amount of the green mass produced. Low fertilizer-corn price ratios allow higher optimum rates of fertilization and larger contributions of nitrogen to the soil than with green manure. Chemical fertilizer also has the advantage of not depleting subsoil moisture as could be the case with green manure.

The second objective of this study was to determine factors which could be limiting nitrogen fertilization to achieve its full potential.

Rainfall during the corn growing critical stages has been frequently mentioned in the Argentine literature as limiting the response to fertilizer. Effects of rainfall and temperatures on corn yields during the 1935-1962 period were analyzed. Low temperatures in October and rainfall before flowering seem to have affected corn yields more than rainfall variability during December (flowering time) and January. High temperatures during January seem to have a more detrimental effect on corn yield even with plenty of subsoil moisture.

The incidence of lack of sufficient rainfall during December and January on the response to fertilizer seems to have been overemphasized without considering other factors that could contribute to subject the corn plant to stress.

Survey data presented in this study suggest that factors other than rainfall could have incidence on the sensitivity of corn plants to temporary summer droughts. Seedbed preparation and cultivation practices followed by the farmers in the study area seem to contribute to deterioration of soil structure and soil compaction, limiting root development and making the corn plant more dependent on rainfall than on stored subsoil moisture.

Research conducted in the U.S. shows that fertilized corn uses subsoil moisture more efficiently through deeper roots and a greater capacity of the roots to extract water from the soil, compensating rainfall deficits during parts of the corn growing stages. Data analyzed by Peterson and

Fienup (40) from experiments carried out in Argentina seem to show similar results. As high doses of nitrogen fertilizer are used on corn, dummy variables reflecting differences in overall growing conditions between years tended to decline in size and significance.

Declines in the fertilizer-corn ratio and adoption of chemical fertilizer by the farmers would result in higher corn yields and lower yield variability due to temporary summer droughts. Rainfall deficits for short periods of time would not affect the corn plant as much as in the past. A deeper root system will mean more subsoil moisture available to the corn plant and less dependence on rainfall.

Dissemination of the information already available on fertilizer response and adoption of chemical fertilizer by the farmers would allow higher corn yields and farm incomes in the area with less fluctuation due to weather conditions.

Survey data also show that farmers in the area follow production practices that under experimental conditions have been shown to produce maximum corn yields. Lack of information does not seem to be the main constraint on improving corn yields. Efforts devoted to disseminate this information are expected to result in low gain in yields unless soil fertility levels are restored with chemical fertilizer. Given the actual production system prevailing in the area and factor-product price relationships, there exists a conflict between the objective function of the farmer and maximization of corn yields. Farmers are more concerned with returns to labor and capital and less concerned with yields per hectare. Declines in the fertilizer-corn price ratio and adoption of chemical fertilizer by the farmers will tend to close that gap. By using chemical fertilizer soil fertility levels could be restored to optimum levels every corn growing season.[1]

The third objective of this study was to determine the gains in production by removing the limiting factors.

Two different situations under available technology were analyzed in this study. Farms with cattle activities and rotations of pastures and farms with low area under pasture. Farms with cattle activities through rotations with pastures were assumed to have soils with high soil fertility levels. The introduction of chemical fertilizer at the prevailing prices during the period covered in this study did not affect optimum farm plans and income even at the most favorable fertilizer-corn price ratio of 3 considered in the model.

Farms with low area under pastures and low soil fertility levels will increase corn production by 13.5 percent using 30 units of nitrogen at a fertilizer-corn price ratio of 9. The value of the program or returns after variable

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[1]Optimum levels of fertilization will depend, assuming perfect certainty, on the marginal productivity of fertilizer and the fertilizer-corn price ratio.

cost will increase by less than 1 percent, after deducting cost of fertilizer, harvesting, marketing and interest on borrowed capital. Declines in the fertilizer-corn price ratio to 3 will result in an increase of 22 and 5 percent on corn yields and income respectively. The value of the program (64056.94 pesos) for this group of farms is below that of corresponding farms with cattle activities (66712.90 pesos). The difference can be accounted for by differences in crop rotations and the extra revenue due to cattle activities.

Under available technology the main impact by a reduction in the price and adoption of nitrogen fertilizer for this group of farmers will be to restore soil fertility levels and increase corn yields comparable to farms with cattle activities.

At levels of fertilization above 30 units of nitrogen per hectare other factors seem to affect larger responses to nitrogen fertilizer for a given price relationship. The development of highly fertilizer-responsive varieties and new production practices, including preemergence herbicides would result in higher corn yields and farm incomes. The area will tend toward crop specialization and most of the area planted under corn will be fertilized.

Given the assumptions of the model differences between farm groups will be minor. Comparing total corn production by farms without cattle activities under the present situation--no chemical fertilizer being used--with total corn production under modern technology using 120 units of nitrogen fertilizer per hectare, total corn production increases by 50 percent. It is assumed that no cattle supplemental feeding technology is available. Assuming cattle are corn fed the total amount of corn delivered to the market will be lower depending on the number of cattle fed.

These figures give some idea of the potential gains from a reduction in the nitrogen-corn price ratio and investment in research to develop a package of practices that will allow nitrogen fertilizer to achieve its full potential.

Before one can extrapolate these results to larger areas and determine the impact on total Argentine corn production further research is needed.

Suggestions for Further Research

Certain assumptions have been made in this study that need further investigation. It has been assumed that there is no response to fertilizer when corn has been planted on fields that have not been under pasture for periods varying from five to eight years. This needs to be tested. Economic response to fertilizer after the second or third year of corn following pasture will have different implications especially on large farms.

Further research on the impact of fertilizer technology in large farms is needed. This study shows that due to the development of highly fertilizer-responsive varieties and supplemental corn feeding technology even though pasture receptivity will increase the level of cattle activities will tend to decline in the study area.

A multi-period analysis will allow a more realistic approach showing the decline of cattle activities and the accumulation of working capital through the different periods.

Estimates of corn demand for feeding cattle together with projections in corn demand in foreign markets will provide more information on what the impact on farm prices might be if there were a large increase in corn production and corn exports by Argentina.

Suggestions for research in agronomy are made in order to provide better data for economic interpretation and recommendations to the farmers.

Experiments carried out under the INTA-CIMMYT-FF program analyzed in this study show that the plant population target was about 50 thousand plants per hectare. This plant population seems to be below the range where nitrogen fertilizer will manifest its full potential under present technology. Fertilizer trials with higher plant populations using the most highly fertilizer-responsive hybrids today available in Argentina could result in higher fertilizer-response at high levels of nitrogen.

Information with respect to previous rotations and years without pasture together with soil chemical analysis will allow a better interpretation of the experimental results.

Information about insects and diseases affecting corn plant development could also provide information that could be related to conditions which subject the corn plant to stress other than rainfall and available soil moisture.

Experimental data available today do not allow one to quantify the contribution to corn yield by the selective herbicide atrazin. Experiments with other preemergence herbicides to control crab-grass should be carried out. Quantification and economic evaluation of these results will allow proper policy recommendations to make them available to the farmers.

Selection of highly fertilizer-responsive hybrids should be included among the objectives of the corn breeding program.

The adoption of chemical fertilizer, use of higher plant population, incorporation of corn stalks into the soil and a shift to continuous corn could bring new disease and insect problems that should be investigated.

The development of a whole package of practices including seedbed preparation, weed control, soil management practices to improve subsoil moisture storage which will reinforce the effect of chemical fertilizer is needed.[1]

Survey information suggests that low soil fertility problems could be more serious in farms in the range between 60 to 120 hectares (group 2). This group represents approximately 38 percent of the farms which planted corn during the 1969 period[2] in the county. This requires more field information about the soil problems in this group. More information about the reaction of the farmers toward the new technology will allow a better implementation of an extension program including agronomic and economic information.

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[1]Marcos Juarez experimental station in INTA is working of different methods of subsoil moisture accumulation. Novelo, P. Marcos Juarez Experimental Station. Personal communication. 1972.

[2]Unpublished 1969 census data, presented in Table 2.5, page 24.

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APPENDIX. THE LINEAR PROGRAMMING MODELS

Table A1. Linear programming matrix for model 1

Identification	Row type[a]	Name
C	N	Income
01	L	Land
02	L	Working capital
03	L	Soybean maximum restraint
04	L	Male calf transfer row
05	L	Female calf transfer row
06	E	Corn harvest transfer row
07	E	Wheat harvest transfer row
07A	L	Wheat selling transfer row
08	L	Corn selling transfer row
09	L	Hog maximum restraint
10	L	TDN March 15 - May 15 transfer row
11	L	TDN May - September transfer row
12	L	TDN September - December transfer row
13	L	TDN December - March 15 transfer row
14	L	Beef selling transfer row
15	L	May 1 - July 15 labor restriction
16	L	July - September 15 labor restriction
17	L	September - November 15 labor restriction
18	L	November - January 30 labor restriction
19	L	February - April 30 labor restriction
20	L	Labor transfer row

[a]In the MPSX routine, N identifies values in the objective function, E means equality restraint and L means less than or equal to.

Table A1 (Continued)

Name						
COLUMNS						
$Wh\text{-}G_4\text{-}C_3$	C	Income	- 47.830	01	Land	1.000
	02	Capital	25.510	06	Corn*[b]	- 12.180
	07	Wheat*	- 2.050	07A	Wheat*	- 2.050
	08	Corn*	- 12.180	10	TDN*	-375.000
	11	TDN*	-250.000	12	TDN*	-575.000
	13	TDN*	-312.000	15	Labor	1.250
	16	Labor	1.010	17	Labor	1.030
	18	Labor	.030	19	Labor	.150
$Wh\text{-}G_4\text{-}C_3\text{-}W/Su_1$	C	Income	- 36.030	01	Land	1.000
	02	Capital	31.530	06	Corn*	- 9.740
	07	Wheat	- 4.300	07A	Wheat*	- 4.300
	08	Corn*	- 9.740	10	TDN*	-450.000
	11	TDN*	-200.000	12	TDN*	-460.000
	13	TDN*	-200.000	15	Labor	1.910
	16	Labor	.850	17	Labor	.830
	18	Labor	.980	19	Labor	.160
$Wh/PP\text{-}PP_4\text{-}C_4\text{-}Wh\text{-}C$	C	Income	- 64.610	01	Land	1.000
	02	Capital	38.140	06	Corn*	- 14.960
	07	Wheat*	- 2.460	07A	Wheat*	- 2.460
	08	Corn*	- 14.960	10	TDN*	-669.000
	11	TDN*	-276.000	12	TDN*	-356.000
	13	TDN*	-421.000	15	Labor	2.070
	16	Labor	1.160	17	Labor	1.250
	18	Labor	.030	19	Labor	.280

[b]Coefficients in starred row names correspond to transfer rows.

Table A1 (Continued)

Name						
Corn	C	Income	- 97.040	01	Land	1.000
	02	Capital	59.060	06	Corn*	- 26.510
	08	Corn*	- 26.510	10	TDN*	-1000.000
	15	Labor	2.720	16	Labor	2.220
	17	Labor	2.750	19	Labor	.400
C-Wh	C	Income	-104.650	01	Land	1.000
	02	Capital	49.010	06	Corn*	- 15.680
	07	Wheat*	- 7.000	07A	Wheat*	- 7.000
	08	Corn*	- 15.680	10	TDN*	-500.000
	13	TDN*	-357.000	15	Labor	3.640
	16	Labor	1.220	17	Labor	1.370
	18	Labor	.100	19	Labor	.750
Wh-PP$_5$-C$_5$-Wh-C$_2$	C	Income	- 71.670	01	Land	1.000
	02	Capital	42.610	06	Corn*	- 15.610
	07	Wheat*	- 1.710	07A	Wheat*	- 1.710
	08	Corn*	- 15.610	10	TDN*	-499.000
	11	TDN*	-429.000	12	TDN*	-506.000
	13	TDN*	-392.000	15	Labor	1.820
	16	Labor	1.380	17	Labor	1.370
	18	Labor	.030	19	Labor	.270
Wh-PP$_5$-C$_5$-Wh/Su	C	Income	- 47.270	01	Land	1.000
	02	Capital	41.250	06	Corn*	- 13.390
	07	Wheat*	- 2.000	07A	Wheat*	- 2.000
	08	Corn*	- 13.390	10	TDN*	-417.000
	11	TDN*	-333.000	12	TDN*	-530.000
	13	TDN*	-690.000	15	Labor	1.670
	16	Labor	1.060	17	Labor	1.150
	18	Labor	.400	19	Labor	.180

Table A1 (Continued)

Name						
C-W/Su	C	Income	- 42.940	01	Land	1.000
	02	Capital	57.330	06	Corn*	- 13.260
	07	Wheat*	- 5.000	07A	Wheat*	- 5.000
	08	Corn*	- 13.260	10	TDN*	-500.000
	15	Labor	3.640	16	Labor	1.060
	17	Labor	1.370	18	Labor	2.390
	19	Labor	.310			
Wheat	C	Income	-102.940	01	Land	1.000
	07	Wheat*	- 14.500	07A	Wheat*	- 14.500
	02	Capital	38.960	13	TDN*	-715.000
	15	Labor	4.570	16	Labor	.230
	18	Labor	.200			
Cow[c]	C	Income	-121.400	02	Capital	8775.600
	04	Calf	- 4.000	05	Calf	- 4.000
	10	TDN	3285.000	11	TDN	7892.000
	12	TDN	3428.000	13	TDN	5111.000
	14	Beef sell.*	-438.500	15	Labor	37.500
	16	Labor	21.100	17	Labor	26.000
	18	Labor	32.600	19	Labor	49.200
	20	Labor	70.000			
Heifer calf	C	Income	- 10.280	05	Calf	1.000
	10	TDN	180.000	11	TDN	12.000
	12	TDN	163.600	13	TDN	296.200
	14	Beef sell.*	-190.000			

[c]One unit corresponds to ten cows.

Table A1 (Continued)

Name						
Steer calf	C	Income	- 10.280	04	Calf	1.000
	10	TDN	180.000	11	TDN	12.000
	12	TDN	163.600	13	TDN	296.200
	14	Beef sell.*	-200.000			
Yearling steer	C	Income	- 4.380	02	Capital	4.380
	04	Yearling	1.000	10	TDN	180.000
	11	TDN	428.000	12	TDN	283.600
	13	TDN	296.200	14	Beef sell.*	-260.000
	15	Labor	7.500	16	Labor	6.000
	17	Labor	1.500			
Steer	C	Income	- 10.660	02	Capital	6.660
	04	Steer	1.000	10	TDN	180.000
	11	TDN	428.000	12	TDN	535.600
	13	TDN	428.200	14	Beef sell.*	-320.000
	15	Labor	7.500	16	Labor	6.000
	17	Labor	6.000	18	Labor	4.500
Slaughter steer	C	Income	- 20.320	02	Capital	13.040
	04	Sl. steer	1.000	10	TDN	462.000
	11	TDN	1004.000	12	TDN	967.600
	13	TDN	698.200	14	Beef sell.*	-420.000
	15	Labor	15.000	16	Labor	7.500
	17	Labor	6.000	18	Labor	7.500
	19	Labor	9.000			

Table A1 (Continued)

Name						
Wheat harvesting	C	Income	- 3.500	07	Wheat	1.000
Wheat selling	C	Income	21.210	07A	Wheat	1.000
Beef selling	C	Income	1.700	14	Beef	1.000
Hogs	C	Income	1500.000	01	Land	.330
	02	Capital	217.180	08	Corn	8.340
	09	Hog	1.000	15	Labor	7.500
	16	Labor	6.100	17	Labor	6.000
	18	Labor	7.600	19	Labor	9.200
Corn selling	C	Income	16.260	08	Corn	1.000
Labor transfer activity	15	Labor	1.000	20	Labor	- 1.000
	16	Labor	1.000	20	Labor	- 1.000
	17	Labor	1.000	20	Labor	- 1.000
	18	Labor	1.000	20	Labor	- 1.000
	19	Labor	1.000	20	Labor	- 1.000
Wh/So-C	C	Income	148.590	01	Land	1.000
	02	Capital	62.300	03	Soyb.	1.000
	06	Corn*	- 14.400	07	Wheat*	- 6.500
	07A	Wheat*	- 6.500	08	Corn*	- 14.400
	15	Labor	3.190	16	Labor	1.600
	17	Labor	1.380	18	Labor	3.110
	19	Labor	.350			
Corn harvesting	C	Income	- 4.210	06	Corn	1.000

Table A1 (Continued)

Name							
RHS[d]							
B	01	Land	95.000	02	Capital	27660.000
B	03	Soybean	40.000	09	Hogs	25.000
B	15	Labor	562.500	16	Labor	412.000
B	17	Labor	499.000	18	Labor	616.000
B	19	Labor	600.000			
ENDATA						

[d]Restrictions in the program.

Table A2. Linear programming matrix for model 2

Identification	Row type[a]	Name
C	N	Income
01	L	Land
02	L	Working capital
03	L	Soybean maximum restraint
06	E	Corn harvest transfer row
07	E	Wheat harvest transfer row
07A	L	Wheat selling transfer row
08	L	Corn selling transfer row
09	L	Hog maximum restraint
15	L	May 1 - July 15 labor restriction
16	L	July - September 15 labor restriction
17	L	September - November 15 labor restriction
18	L	November - January 30 labor restriction
19	L	February - April 30 labor restriction

Name						
COLUMNS						
Corn	C	Income	- 97.040	01	Land	1.000
	02	Capital	59.060	06	Corn*[b]	- 26.510
	08	Corn*	- 26.510	10	TDN*	-1000.000
	15	Labor	2.720	16	Labor	2.220
	17	Labor	2.750	19	Labor	.400

[a]In the MPSX routine, N identifies values in the objective function, E means equality restraint and L means less than or equal to.

[b]Coefficients in starred row names correspond to transfer rows.

Table A2 (Continued)

Name						
C-Wh	C	Income	-104.650	01	Land	1.000
	02	Capital	49.010	06	Corn*	- 15.680
	07	Wheat*	- 7.000	07A	Wheat*	- 7.000
	08	Corn*	- 15.680	10	TDN*	-500.000
	13	TDN*	-357.000	15	Labor	3.640
	16	Labor	1.220	17	Labor	1.370
	18	Labor	.100	19	Labor	.750
C-Wh/Su	C	Income	- 42.940	01	Land	1.000
	02	Capital	57.330	06	Corn*	- 13.260
	07	Wheat*	- 5.000	07A	Wheat*	- 5.000
	08	Corn	- 13.260	10	TDN	-500.000
	15	Labor	3.640	16	Labor	1.060
	17	Labor	1.370	18	Labor	2.390
	19	Labor	.310			
Wheat	C	Income	-102.940	01	Land	1.000
	07	Wheat*	- 14.500	07A	Wheat	- 14.500
	02	Capital	38.960	13	TDN*	-715.000
	15	Labor	4.570	16	Labor	.230
	18	Labor	.200			
Wheat harvesting	C	Income	- 3.500	07	Wheat	1.000
Wheat selling	C	Income	21.210	07A	Wheat	1.000
Borrowing capital	C	Income	- .080	02	Capital	- 1.000

Table A2 (Continued)

Name						
Hogs	C	Income	1500.000	01	Land	.330
	02	Capital	217.180	08	Corn	8.340
	09	Hog	1.000	15	Labor	7.500
	16	Labor	6.100	17	Labor	6.000
	18	Labor	7.600	19	Labor	9.200
Corn selling	C	Income	16.260	08	Corn	1.000
Wh/So-C	C	Income	148.590	01	Land	1.000
	02	Capital	62.300	03	Soyb.	1.000
	06	Corn*	- 14.400	07	Wheat*	- 6.500
	07A	Wheat*	- 6.500	08	Cron*	- 14.400
	15	Labor	3.190	16	Labor	1.600
	17	Labor	1.380	18	Labor	3.110
	19	Labor	.350			
Corn harvesting	C	Income	- 4.210	06	Corn	1.000
RHS[c]						
B	01	Land	95.000	02	Capital	5000.000
B	03	Soybean	40.000	09	Hogs	24.000
B	15	Labor	562.500	16	Labor	412.000
B	17	Labor	499.000	18	Labor	616.000
B	19	Labor	600.000			
ENDATA						

[c]Restrictions in the program.

Table A3. Input-output coefficient matrix for available technology[a,b]

Name						
Wh-R.Cl-C	C	Income	- 88.970	01	Land	1.000
	02	Capital	39.080	06	Corn*[c]	- 15.900
	08	Corn*	- 15.900	07	Wheat*	- 6.500
	07A	Wheat*	- 6.500	10	TDN*	-100.000
	11	TDN*	- 80.000	13	TDN*	- 90.000
	15	Labor	2.280	16	Labor	2.090
	17	Labor	1.380	18	Labor	.100
	19	Labor	.250			
Wh-GV-C	C	Income	-123.420	01	Land	1.000
	02	Capital	73.690	06	Corn*	- 15.240
	08	Corn*	- 15.240	07	Wheat*	- 8.200
	07A	Wheat*	- 8.200	11	TDN*	-100.000
	15	Labor	2.280	16	Labor	2.090
	17	Labor	1.380	18	Labor	.100
	19	Labor	2.130			
C-GV-C	C	Income	-138.730	01	Land	1.000
	02	Capital	96.940	06	Corn*	- 29.160
	08	Corn*	- 29.160	16	Labor	3.410
	17	Labor	2.790	19	Labor	3.190

[a]Activities added to model 1 and 2.

[b]Fertilizer-corn price ration equal to 9.

[c]Coefficients in starred row names correspond to transfer rows.

Table A3 (Continued)

Name						
C_{20N}[d]	C	Income	-129.410	01	Land	1.000
	02	Capital	91.430	06	Corn*	- 29.790
	08	Corn*	- 29.790	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.400
	19	Labor	.500			
C_{30N}	C	Income	-144.040	01	Land	1.000
	02	Capital	106.060	06	Corn*	- 31.150
	08	Corn*	- 31.150	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.450
	19	Labor	.500			
C_{40N}	C	Income	-158.670	01	Land	1.000
	02	Capital	120.690	06	Corn*	- 32.200
	08	Corn*	- 32.200	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.500
	19	Labor	.600			
C_{50N}	C	Income	-173.300	01	Land	1.000
	02	Capital	135.320	06	Corn*	- 33.030
	08	Corn*	- 33.030	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.550
	19	Labor	.600			
C_{60N}	C	Income	-187.930	01	Land	1.000
	02	Capital	149.950	06	Corn*	- 33.710
	08	Corn*	- 33.710	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.600
	19	Labor	.700			

[d]Corn activity subscript corresponds to the number of units of nitrogen per hectare.

Table A3 (Continued)

Name						
C_{70N}	C	Income	-202.560	01	Land	1.000
	02	Capital	164.580	06	Corn*	- 34.310
	08	Corn*	- 34.310	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.650
	19	Labor	.700			
C_{80N}	C	Income	-217.190	01	Land	1.000
	02	Capital	179.210	06	Corn*	- 34.730
	08	Corn*	- 34.730	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.700
	19	Labor	.800			
C_{90N}	C	Income	-231.820	01	Land	1.000
	02	Capital	193.840	06	Corn	- 34.980
	08	Corn*	- 34.980	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.750
	19	Labor	.800			

Table A4. Input-output coefficient matrix for available technology[abc]

Name						
C_{20N}	C	Income	-122.950	01	Land	1.000
	02	Capital	85.090	06	Corn*	- 29.790
	08	Corn*	- 29.790	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.400
	19	Labor	.500			
C_{30N}	C	Income	-134.350	01	Land	1.000
	02	Capital	96.550	06	Corn*	- 31.150
	08	Corn*	- 31.150	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.450
	19	Labor	.500			
C_{40N}	C	Income	-145.750	01	Land	1.000
	02	Capital	108.010	06	Corn*	- 32.200
	08	Corn*	- 32.200	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.500
	19	Labor	.600			
C_{50N}	C	Income	-157.150	01	Land	1.000
	02	Capital	119.470	06	Corn*	- 33.030
	08	Corn*	- 33.030	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.550
	19	Labor	.600			

[a]Activities added to model 1 and 2.

[b]Fertilizer-corn price ratio equal to 7.

[c]Coefficients for green manure activities remain the same as in Table A3 and are not presented from now on.

Table A4 (Continued)

Name						
C_{60N}	C	Income	-168.550	01	Land	1.000
	02	Capital	130.930	06	Corn*	- 33.710
	08	Corn*	- 33.710	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.500
	19	Labor	.700			
C_{70N}	C	Income	-179.950	01	Land	1.000
	02	Capital	142.390	06	Corn*	- 34.310
	08	Corn*	- 34.310	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.650
	19	Labor	.700			
C_{80N}	C	Income	-191.350	01	Land	1.000
	02	Capital	153.850	06	Corn*	- 34.730
	08	Corn*	- 34.730	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.700
	19	Labor	.800			
C_{90N}	C	Income	-202.750	01	Land	1.000
	02	Capital	165.310	06	Corn*	- 34.980
	08	Corn*	- 34.980	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.750
	19	Labor	.800			

Table A5. Input-output coefficient matrix for available technology[a]

Name						
C_{20N}	C	Income	-116.410	01	Land	1.000
	02	Capital	78.430	06	Corn*	- 29.790
	08	Corn*	- 29.790	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.400
	19	Labor	.500			
C_{30N}	C	Income	-124.540	01	Land	1.000
	02	Capital	86.560	06	Corn*	- 31.150
	08	Corn*	- 31.150	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.450
	19	Labor	.500			
C_{40N}	C	Income	-132.670	01	Land	1.000
	02	Capital	94.690	06	Corn*	- 32.200
	08	Corn*	- 32.200	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.500
	19	Labor	.600			
C_{50N}	C	Income	-140.800	01	Land	1.000
	02	Capital	102.820	06	Corn*	- 33.030
	08	Corn*	- 33.030	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.550
	19	Labor	.600			

[a]Fertilizer-corn price ratio equal to 5.

Table A5 (Continued)

Name						
C_{60N}	C	Income	-148.930	01	Land	1.000
	02	Capital	110.950	06	Corn*	- 33.710
	08	Corn*	- 33.710	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.600
	19	Labor	.700			
C_{70N}	C	Income	-157.060	01	Land	1.000
	02	Capital	119.080	06	Corn*	- 34.310
	08	Corn*	- 34.310	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.650
	19	Labor	.700			
C_{80N}	C	Income	-165.190	01	Land	1.000
	02	Capital	127.210	06	Corn*	- 34.730
	08	Corn*	- 34.730	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.700
	19	Labor	.800			
C_{90N}	C	Income	-173.320	01	Land	1.000
	02	Capital	135.340	06	Corn*	- 34.980
	08	Corn*	- 34.980	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.750
	19	Labor	.800			

Table A6. Input-output coefficient matrix for available technology[a]

Name						
C_{20N}	C	Income	-109.900	01	Land	1.000
	02	Capital	71.920	06	Corn*	- 29.790
	08	Corn*	- 29.790	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.400
	19	Labor	.500			
C_{30N}	C	Income	-114.770	01	Land	1.000
	02	Capital	76.790	06	Corn*	- 31.150
	08	Corn*	- 31.150	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.450
	19	Labor	.500			
C_{40N}	C	Income	-119.640	01	Land	1.000
	02	Capital	81.660	06	Corn*	- 32.200
	08	Corn*	- 32.200	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.500
	19	Labor	.600			
C_{50N}	C	Income	-124.510	01	Land	1.000
	02	Capital	86.530	06	Corn*	- 33.030
	08	Corn*	- 33.030	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.550
	19	Labor	.600			

[a]Fertilizer-corn price ratio equal to 3.

Table A6 (Continued)

Name						
C_{60N}	C	Income	-129.380	01	Land	1.000
	02	Capital	91.400	06	Corn*	- 33.710
	08	Corn*	- 33.710	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.600
	19	Labor	.700			
C_{70N}	C	Income	-134.250	01	Land	1.000
	02	Capital	96.270	06	Corn*	- 34.310
	08	Corn*	- 34.310	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.650
	19	Labor	.700			
C_{80N}	C	Income	-139.120	01	Land	1.000
	02	Capital	101.140	06	Corn*	- 34.730
	08	Corn*	- 34.730	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.700
	19	Labor	.800			
C_{90N}	C	Income	-143.990	01	Land	1.000
	02	Capital	106.010	06	Corn*	- 34.980
	08	Corn*	- 34.980	15	Labor	2.720
	16	Labor	2.220	17	Labor	3.750
	19	Labor	.800			

Table A7. Input-output coefficient matrix for highly fertilizer-responsive hybrids and supplemental feeding[a] (model 1A[b])

Name						
Corn feeding	08	Corn*	1.000	11	TDN	- 80.000
	15	Labor	1.000	16	Labor	1.000
Corn feeding	08	Corn*	1.000	12	TDN	- 80.000
	17	Labor	1.000	18	Labor	1.000
Corn feeding	18	Labor	1.000	19	Labor	1.000
	08	Corn*	1.000	13	TDN	- 80.000
Corn feeding	15	Labor	1.000	19	Labor	1.000
	08	Corn*	1.000	10	TDN	- 80.000
Hiring labor	C	Income	- 1.550	15	Labor*	- 1.000
Hiring labor	C	Income	- 1.550	16	Labor*	- 1.000
Hiring labor	C	Income	- 1.550	17	Labor*	- 1.000
Hiring labor	C	Income	- 1.550	18	Labor*	- 1.000
Hiring labor	C	Income	- 1.550	19	Labor*	- 1.000

[a]Activities added to model 1.

[b]In model 1B supplemental feeding and hiring labor activities were not included.

Table A7 (Continued)

Name						
C_{30N}	C	Income	-145.560	01	Land	1.000
	02	Capital	100.160	06	Corn*	- 35.860
	08	Corn*	- 35.860	16	Labor	2.880
	17	Labor	3.360	19	Labor	2.620
C_{60N}	C	Income	-160.190	01	Land	1.000
	02	Capital	114.790	06	Corn*	- 41.140
	08	Corn*	- 41.140	16	Labor	2.880
	17	Labor	3.360	19	Labor	2.620
C_{90N}	C	Income	-174.820	01	Land	1.000
	02	Capital	129.420	06	Corn*	- 45.000
	08	Corn*	- 45.000	16	Labor	2.880
	17	Labor	3.360	19	Labor	2.620
C_{120N}	C	Income	-189.450	01	Land	1.000
	02	Capital	144.050	06	Corn*	- 47.300
	08	Corn*	- 47.300	16	Labor	2.880
	17	Labor	3.360	19	Labor	2.620